NOVEMBER, 1960

Welding Journal

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Schoonmaker Appointed Editor of Welding Journal

T. P. Schoonmaker, former technical information administrator of the Linde Co., became editor of the WELDING JOURNAL on Oct. 1, 1960. He succeeds Bonney E. Rossi, former editor, who has resigned to assume new duties as executive secretary of the Society for Experimental Stress Analysis. This action was announced on August 23rd by Fred L. Plummer, national secretary of AWS.

Mr. Schoonmaker will have complete responsibility for all JOURNAL operations—editorial and business—and will also serve as secretary of the Technical Papers Committee of AWS. Mr. Rossi will be available on a part-time consulting basis for several months to effect the transition without change in JOURNAL policy. In all other respects the publication will continue exactly as before.

To his new position, Mr. Schoonmaker brings a varied background in technical writing, editing and market analysis, particularly in regard to research and development in the welding field. In World War II, he saw early action with the Army Air Corps in the Middle East, having received his commission in 1942. Shot down over Naples in 1943, he spent the rest of the war in Italian and German prison camps until being liberated by the Third Army in 1945.

T. P. Schoonmaker

Attending Harvard University, he won his degree in chemistry in 1946 and in the following year joined Union Carbide Corp. as a technical writer. Upon receiving his M.B.A. in statistics and marketing from Columbia University in 1951, he engaged in statistical studies for the Linde Co., Division of Union Carbide Corp. He was transferred to the Development Laboratory of Linde in 1955 where he has since been in charge of technical information activities.

Active in civic affairs, Mr. Schoonmaker resides in Glen Ridge, N. J., with his wife, Gloria, and their 3-year old son.

RWMA Reports High Shipments

Resistance welding equipment shipments for the month of August went above the $2.5 million mark for the fourth month this year, according to the regular statistics compiled each month by the Resistance Welder Manufacturers' Association.

It was the seventh consecutive month in which shipments were above $2 million and, at the end of August, shipments for 1960 showed a 16% increase over the first eight months of 1959. While new business during the month of August was down from July, the total of new orders for the first two-thirds of the year was still ahead almost 10% over the similar period last year. A backlog of more than $10 million was reported by the members of the association at the end of August.

NEMA Welding Controls Standard

The National Electrical Manufacturers Association has issued a revised standard for resistance-welding control equipment to help users select the proper controls.

The new standard "Resistance Welding Control—IC-2-1960" includes definitions and cycle diagrams for all generally used resistance-welding processes. Definitions and diagrams are cross-referenced with a master table listing NEMA identification numbers for the control equipment required to perform each of the described functions. All major control manufacturers list this equipment by NEMA number, as well as their own model or type numbers.

Also listed are minimum standards for such factors as accuracy, time range, size, and capacity, which are widely used in the industry. Separate sections are included for frequency converter controls, gun welder controls and multifunction process timers.

Copies are available from the Association's office, 155 East 44th Street, New York 17, N. Y., at $1.00 per copy.

Branson Acquires Interests

In a recent expansion and diversification move, Branson Instruments, Inc., Stamford, Conn., has acquired Colin Campbell Co., Inc., Danbury, Conn., through exchange of stock. Also, by cash payment, Branson has obtained a half-interest in Radionics, Inc., Norristown, Pa.

The Danbury firm, now a wholly-owned subsidiary, manufacturers transformers, toroids and other electronic devices for defense and industrial applications. Radionics makes gamma radiography thickness gages and flaw detectors, which complement similar ultrasonic-powered test equipment produced by the parent company. Branson Ultrasonic Corp., also of Stamford, is another wholly-owned subsidiary, manufacturing ultrasonic cleaning equipment.

Gregory Reports Earnings

Gregory Industries, Inc., manufacturers of Nelson stud welding and stud driving equipment and fasteners and Bulldog concrete anchors, recently reported earnings of $93,762, equivalent to 27 cents per share for the first quarter of its fiscal year (May through July).

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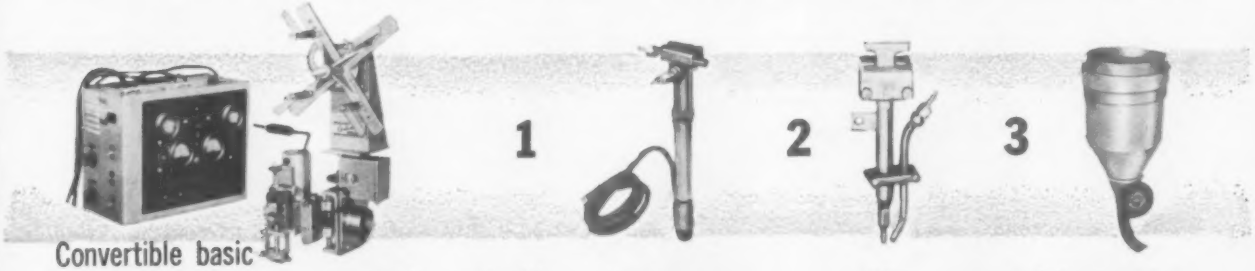

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WELDING ZONES

United Engineering Center—New AWS Home . . .

Welding the reinforcement around web cut-out on a 10-ton built-up girder at the Dreier shop in Long Island City, N. Y. General Contractor is the Turner Construction Co.

Columns varied in size according to wind loads. Here the milled-end joint of a heavy section is welded

Beam-to-column connections and column joints are welded as the building frame rises

Next to 22-ton truss, the transition joint between flange plates of a girder is welded at the Dreier Structural Steel Co., L. I. City, N. Y.

WHICH WAY?

There are many ways to weld, but you want the one that *best* fits your needs. Your choice is determined by metals, thicknesses, designs, joints...and your fabricating objectives—economy, quality, speed, strength, appearance, precision. Which welding process should you use? Tig? Mig? CO_2? Spot welding? Manual, semi-, or fully-automatic? Would a cutting process simplify production? Correct answers to these questions require experience with the major arc welding and cutting processes—from submerged arc to plasma arc—introduced during the past 25 years. LINDE has *all* of these processes. No other company does. In fact, LINDE *introduced* almost all of them...and *improved* the rest. Consequently, LINDE has far more experience with tungsten-arc cutting, inert-gas welding, and continuously-fed electrode welding than any other company in the world. In many cases, these processes are ideal. In some, they are even a necessity. Because we have all of them, we recommend only the one that *best* fits your needs. When making your choice, bear in mind that a recommendation from an equipment manufacturer is apt to be *only as accurate as the completeness of his line*.

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

AUSTRIA

The butt welding of railway rails by means of low-hydrogen electrodes is described in the Austrian magazine *Schweisstechnik* for October 1959. A total of 18 electrodes is used per joint, a 6016 type being used for the foot and web, and 8016 type being used for the head. The rails are spaced $^{5}/_{8}$ in. apart and a copper mold is used.

A theoretical treatment of bending and torsional stresses in welded unsymmetrical box beams is given in the December 1959 issue of the Krupp technical magazine. Equations are developed suitable for use in a computer.

The application of the brittle varnish method of revealing stress concentrations in welded structures is described in *Stahl und Eisen*, Feb. 4, 1960 issue. The method is applied particularly to welded cranes, where the trend toward thinner sections is increasing. Methods of design based on stress calculations are said to be hopeless, while design based on the fields of stress revealed that the brittle varnish leads to satisfactory results.

BELGIUM

The Belgian *Revue de la Soudure* for the first quarter of 1960 contains the first part of a continuing article on microfissures in mild-steel welds. The article distinguishes among hot tears which are colored and occur only a few hundred degrees below the melting point, cold cracks which are audible and not colored, and microfissures which are only 0.006–0.012 in. long and 0.00004 in. wide. This first part reviews literature on hydrogen in steel including Flanigan's work and static fatigue. The paper will be the basis for research sponsored by the Belgian Institute of Welding.

CZECHOSLOVAKIA

The Czech welding magazine *Zvaranie* for November 1959 contains the following articles:

1. A comparison of crack tests for welded austenitic stainless steels showed that simple bend test of a longitudinal weld was adequate for revealing fissures.

2. The fatigue strength of welds containing known high residual stress was found to be as much as 24% lower than for welds free from residual stress. Steel $^{1}/_{4}$ in. thick showed little effect, but for steel $1^{3}/_{16}$ in. thick the maximum reduction in fatigue strength occurred.

3. The welding of brass strip in a rolling mill was accomplished by the tungsten-arc process with argon.

The December 1959 issue contained these articles:

1. A flux-filled tubular electrode with a central wire has been developed for welding mild steel in CO_2.

2. Manual electroslag welding of steel with $^{1}/_{4}$-in. covered electrodes is described. The process is used for butt welding rails.

3. Tests on longitudinal fillet welds showed that biaxial stresses must be considered in circumstances in which the weld does not reach the yield stress at any point, as in fatigue. It is unnecessary to take account of the second principal stress, if there is opportunity for plastic redistribution of stress under load.

4. The results of development and research on CO_2 welding of steel at the Bratislava Welding Institute are summarized including feed rolls, power supply characteristics, wire (0.8–1.9 Mn, 0.6–1.0 Si) and oscillography.

5. Electroslag welds in 0.40% C steel 10 in. thick had a rotating bend fatigue strength of 17,000–20,000 psi, which was 1500 psi below the unwelded steel. The weld contained 0.24 C, 1.15 Mn, 0.27 Si.

6. Auto-radiography of spot welds in rimmed steel revealed a fairly uniform distribution of carbon.

7. The production of sprayed ferro-tungsten for filling tubular welding wire is described. The product contained 55–65 W, 0.4–0.7 C, 1–2 O_2, rest Fe.

FRANCE

Soudage, the French Institute of Welding magazine, contains the following articles in its January-February 1960 issue.

1. The metallurgy and welding of plain chromium steels from 1 to 13% Cr are reviewed with special emphasis on 5% Cr steel. For Type 502 steel, better notch impact value was secured with weld metal containing 0.25% Si than with 1.5 Si. Excessively high preheat (1020° F) lowered the notch-impact value considerably compared with 570° F. The author does not favor the use of Type 310 weld metal for chromium steels, but prefers weld metal of the same composition as base metal with a high-temperature draw (1200–1400° F) after welding.

2. In the welding of a 2500-ton box-section bridge at Lyons, France, the shop sequence was set down in great detail to minimize residual stress. Plates and low-hydrogen weld metal were required to pass a notch impact test at 32° F. The bridge contained 41 miles of welding and 190,000 rivets.

3. The French Ministry of Industry has revised and completed its code for welded pressure vessels. Several new steels are approved, and restrictions on certain types of welds are relaxed.

4. The French Society of Welding Engineers increased their membership by 54 to a total of 1311 members during 1959. President for 1960 is P. Blanc.

EAST GERMANY

ZIS Mitteilungen published by the Central Welding Institute (ZIS) of East Germany have been received for November 1959 to February 1960.

The November 1959 issue contains six articles on light steel construction and a note on program control of tungsten inert-gas welding. The structural laboratories of ZIS have equipment for testing the buckling of web plates, the column strength of tubular struc-

Dr. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

welding costs cut 31% to 51%*

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A recent test matched Pureco CO_2 Weld Shielding against three other methods: Two with manual stick electrodes—one with manual submerged arc. Each made an identical 100 ft., ¼" fillet weld. CO_2 traveled 40 inches per minute against 21.4 ipm for the fastest stick electrode. CO_2 deposited 21 lbs. of metal per hour compared to 11.4 lbs. for submerged arc and 9.81 lbs. for the fastest stick electrode. Considering *all cost elements*, including overhead—Pureco CO_2 Weld Shielding was 31 to 51% less than the others.

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Pureco CO_2 *Weld Shielding* is ideal for both single and multi-pass applications, manual or automatic, with large or small diameter wires . . . CO_2 can now be used for position manual welding, too!

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tures and the fatigue strength of a variety of parts. The largest impact tester is 22,000 ft-lb capacity, and there is an impact photoelastic instrument. The pulsating stress fatigue strength of tubular trusses without gusset plates but with butt welds made by the CO_2 process with backing rings was found to be 15,700 psi. A comparison of experimental with calculated strengths of fillet welds in torsion showed that tests results were 25 to 70% higher than calculated. Fatigue tests of designs of rigid frames showed that rounded knees had a fatigue strength up to 11,000 psi, compared with 3500 psi for square knees. The damping capacity of spot-welded and arc-welded structures was 100% higher if the design provided for rubbing surfaces held in contact by the welds.

The December 1959 issue contains four articles on submerged-arc welding. The first article shows that low-alloy steel St 52 (74,000 psi tensile strength) can be welded without preheat in thicknesses up to 1 in. Strength and notch impact value were found to depend to a great extent on joint design and type of wire and flux. The second article is in handbook style and describes the wires and fluxes used in East Germany and the recommended joint designs and welding conditions for butt and fillet welds. The third article illustrates the value of supplementary magnetic fields to prevent arc blow in welding with direct current. The fourth article describes tubular electrodes for submerged-arc hard facing.

The January 1960 issue contains 14 articles on welding plastics and adhesives for metals. The principal articles on plastics discuss hot plates for welding polyethylene, and the technique of forming glass fiber reinforced plastics. Shear, pry, creep, fatigue and weathering tests for adhesives are described.

The February 1960 issue is devoted principally to tungsten inert-gas welding. Much of the information is instructional and illustrates the range of application of the process. There are separate sections on spot welding with a tungsten electrode, on constricted-arc cutting of aluminum, and on welding stainless steels and titanium. Equipment is described for stud welding with argon protection, straight polarity, and a steel stud up to $^1/_2$ in. diam.

WEST GERMANY

Research on welded traveling cranes of thin-walled mild steel box section design is reported in the Dec. 24th issue of the West German magazine *Stahl und Eisen*. Cranes of 10, 70 and 120 ton capacity were studied. Static and impact stresses were measured. The stress was surprisingly uniformly distributed over the box sections. Only a few points of stress concentration were found. Normal stresses generally were higher than shear stresses. The location of welds away from points of maximum stress is illustrated.

The West German Welding Society began publication of an 8-page supplement to its magazine *Schweissen und Schneiden* in January 1960. The supplement is called the "Practical Welder and Cutter" and is pasted to the front page of the magazine. The first issue discusses: (1) the disadvantages of combining rivets or bolts with welding in the same joint, (2) a clamp for holding small parts during welding, (3) the descriptive geometry of intersecting cones and cylinders and (4) the amount of acetylene evolved by a pound of carbide.

The following articles appear in *Schweissen und Schneiden*.

1. A dissertation from the Hanover Technical College describes an investigation of soft soldered joints in mild steel, copper and brass. The test specimen was a pin soldered into a hole. With lead-tin solders the shear strength was 25% higher with air cooling than with water quenching. Soldered joints in copper had 10 to 20% higher strength than in steel. As the clearance increased beyond 0.002 in., the strength decreased. Constant-load tests at temperatures up to 300° F showed that strength decreased steadily with increase in temperature but approached a constant value with increase in time. The fatigue strength was higher under reversed stress than under pulsating stress because creep was adding to the pulsating stress. The ratio of shear strength to tensile strength for soldered joints with four solders was 0.42 to 0.71. The tensile strength of a joint made with a cadmium-zinc solder containing 10% silver was 29,000 psi compared with 14,500 psi for the best lead-tin solder. Electron micrographs showed that adhesion was the principal source of strength in soldered joints but that alloying by diffusion also contributed.

2. Fatigue tests showed that the endurance limit of a notched shaft can be raised 20 to 35% by depositing weld metal of lower modulus of elasticity than base metal at the root of the notch. Rotating bend fatigue tests were made on notched steel cylinders, the metal in the vicinity of the notch being deposited by Cr-Ni-Mn and aluminum bronze electrodes. The notched specimens of drawn steel, 88,000 psi tensile strength, had an endurance limit of 25,000 psi, compared with 30,000 to 32,000 psi for the specimens notched in a surface layer of low-modulus weld metal.

3. Stored-energy arc resistance welding by means of condensers now is more economical than by inductance. Small machines up to 225 w sec capacity are available, as well as large machines up to 12,000 w sec. The stored-energy machine has the advantages of accurate control of welding energy, minimum line loading and freedom from line voltage variations.

4. Techniques for repairing cast iron and steel parts are discussed. A cast iron compressor cylinder was preheated red hot, welded with an electrode of cast iron and cooled slowly to room temperature over a period of 3 days. Patches in boiler drums required close attention to sequence of welding. Submerged-arc welding was used to build-up railway wheels and pump plungers.

5. The Aachen Technical College opened a new building for its Institute for Production Welding Processes in October 1959. The Institute Director is Alfred Henning. The Institute gave its first welding course in 1924, when experiments were made with dipped electrodes. The Institute occupies 22,500 sq ft of floor space. The building cost 72 cents per cubic ft and was financed 78% by the government. Laboratories are equipped for gas, resistance and arc welding, induction heating and materials testing.

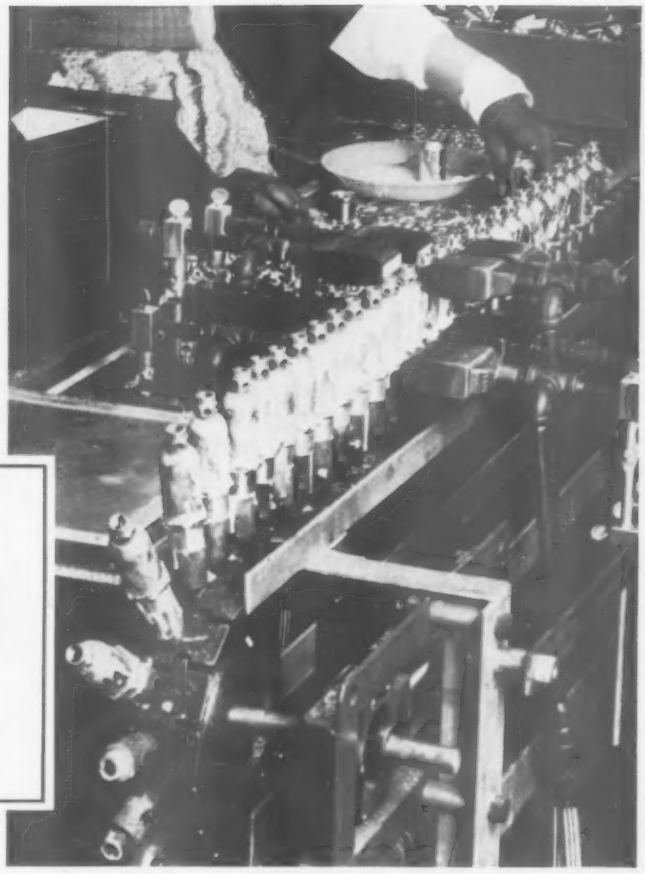
6. At the Plastics Exposition in Dusseldorf, October 1959, equipment for welding plastics by the hot gas, hot plate, high frequency and friction processes was exhibited. Machinery for sealing polyethylene containers utilized the heat-impulse system.

7. The Welding Design Committee of the German Welding Society issued a series of 26 sketches of pipe-flange connections.

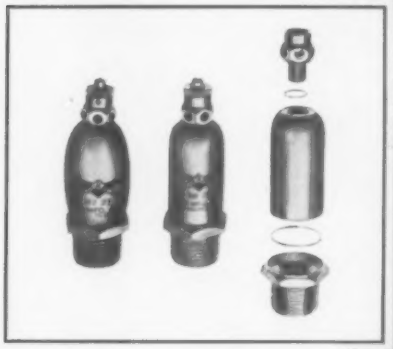
YUGOSLAVIA

The Yugoslav magazine *Varilna Tehnika*, No. 4, 1959, contains articles reviewing foreign developments in welding, but also briefly discusses distortion and welding sequence in building small ships.

Operator dips parts in HANDY FLUX and assembles them with EASY-FLO 45 rings on a moving rig. Assemblies then pass between banks of gas burners to complete brazing process. Capillary action of EASY-FLO brazing alloy insures thorough penetration—guarantees high strength, leakproof joints.



Flair No. 21 Hot Water Air Vent consists of the basic free-venting air valve, a generous air-collection chamber and a massive hex base. Two preform rings of EASY-FLO 45 are used in the brazing operation. Valve assembly at left was subjected to extreme pressure. Note how body ballooned; joints strong and leaktight.



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Never a field failure in any joint brazed with EASY-FLO 45 and HANDY FLUX—that's the proud record of Flair Manufacturing Company, Brooklyn, New York, makers of an extensive line of air valves and other specialties for steam and hot-water systems.

Flair finds that brazing with EASY-FLO 45 offers competitive advantages in every aspect of design, production economy and service life. Big savings are made through elimination of costly casting equipment and more productive use of space. Production is smoother, faster. Valves look better, last longer... in tests to 5000 psi, valve bodies burst while brazed joints remain intact. All this for an alloy cost per unit of approximately 2½¢ for two preform rings of EASY-FLO 45.

Speed, strength, economy, low labor costs—advantages *any* manufacturer would be glad to have. And, all achieved through use of Handy & Harman silver alloy brazing. Chances are silver alloy brazing could benefit your product too. If it could, or if you think it *might*, don't hesitate to get in touch with Handy & Harman. We'll help you in every way possible. Why not call us today?

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How Ni-Rod "55" builds up worn cast iron... keeps repair cost down

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These engineers in turn recommended a Ni-Rod "55"* repair job – welding to be done by Welding Engineers Ltd., Montreal.

Wear ran as high as ⅛ inch on some of the piston ring grooves. But with Ni-Rod "55" Electrodes, welders soon had all six pistons back in the ship at a total cost of $2,450 – a saving of over $4,750.

How they did the job with Ni-Rod "55"

Using Ni-Rod "55" Electrodes, they welded cast iron inserts into position on the pistons to offset the worn areas. The pistons were pre-heated to 500° F and each of the 6 inserts welded into position with two passes by manual arc-welding. After welding, the pistons were covered with asbestos to cool. Ni-Rod "55" eliminated the need for post-heating. Then the pistons were machined and returned to the engine.

For your jobs

Ni-Rod "55" can be used to build up worn areas in almost all cast iron parts. Auto, truck, or ship pistons... valve seats... cylinder walls... are just a few. And the cost is just a fraction of what replacement would cost. What's more, with Ni-Rod "55", the repair is done quickly and easily. Welds are strong, sound, highly machinable.

Keep Ni-Rod "55" in mind for building up worn areas on cast iron parts. Even better, have a supply of these electrodes on hand. Look in your classified directory under "Nickel" for your local supplier.

And *write* for "Repair Cast Iron Parts Quickly and Easily" for the complete Ni-Rod "55" story.

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Impact of the Human Element

Welding is progressing in such rapid strides throughout the industry—with the missile field as an example—that we would strongly urge a review of the various welding codes so as to modernize them even beyond their present status.

There have been tremendous advances in welding, itself, and in the development of materials such as the more recent stainless steels. However, control over the human element in welding has not undergone a parallel advancement. Thus end results remain up to the individual welding operator despite the excellent equipment produced by welding process and machine manufacturers and despite the way in which welding electrode suppliers can make an excellent product for joining high-grade materials produced under close control by the steel mill.

Against the background of high-operating costs and the use of premium materials, it seems logical that a simple set of tests could be devised to make sure that personnel carrying out the welding operation will actually produce the quality of workmanship required in the job. On the other hand, so many factors in a man's life control his workmanship that a company can never depend entirely on his ability alone to turn out quality work. This, I realize, is a factor of the human element. Yet we can pay a rather large price for the present type of test plates required to qualify welders for jobs of a specialized nature as encountered in the fabrication of liquefied gas containers. And many times when a man makes up an excellent set of test plates, he may still produce poor work on the job because of any one of many personal reasons. Here the company suffers tremendously because of something over which there is yet no control. This leads us to believe that a company making products such as now produced in the plants of our own organization will have to concern itself—more so than in the past—with the daily activities of its men.

We think that close study on the part of code committees may at least partially help to remedy the situation as outlined here, particularly since today's knowledge of welding exceeds that which existed when some of the codes were written.

Robert G. Biesel

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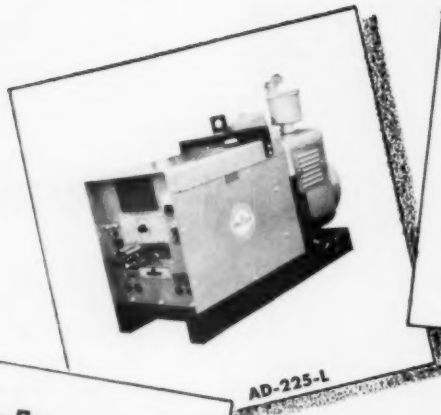

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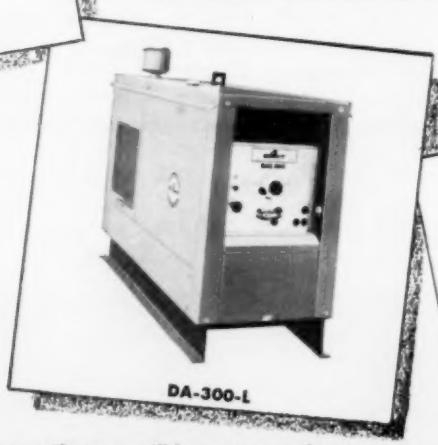

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Welding of High-Strength Low-Alloy Structural Steel for **Bridges**

Carquinez Bridge—new welded structure on right

can be performed successfully if proper welding procedures are established and closely followed during fabrication

BY JOHN L. BEATON AND PAUL G. JONAS

The use of weldable alloy steels is relatively new to the bridge construction field in California. Less than five years ago little use was made of such materials as major stress carrying members in welded bridges. However, the California Division of Highways was making wide use of low-carbon structural steel in that practically all highway bridges were and are of welded fabrication. Now the bridge designers of California utilize high-strength alloy steels in well over half of their designs. The use of welded structures started in this State about 20 years ago and slowly developed to the point where, since 1950, most steel structures are completely welded. At present the bridge program requires between 30,000 and 40,000 tons of structural steel of all types annually.

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Paper presented at AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

The steel industry is to be congratulated for making new alloy steels available for the use of the construction industry and thereby meeting competition from other types of materials. It is still necessary, however, for the industry to develop a nonproprietary low-alloy steel with good welding characteristics in the 42,000 to 50,000 psi yield point range. This is desirable so that an engineer can specify such steel with confidence of fulfilling his requirements. At the present time, structural steels in this range are covered by ASTM A242 specifications. This is a catch-all specification covering steels with good corrosion characteristics or good weldability or, perhaps, a mixture of both traits. Unfortunately, the steels furnished to this specification are proprietary and the chemical requirements of the specification are inadequate to inform the user concerning welding characteristics of the material before the actual supplier is known. At present, an ASTM Commit-

tee is developing a specification which appears to consider the user's requirements. From a user's viewpoint, these requirements are rather simple; they are (1) that the engineer can read the steel specification and know that it will furnish a weldable steel that will satisfy the needs of the structure and its environment, and (2) that a fabricator or erector can be assured that, no matter who furnishes the steel, his established welding procedures and costs are adequate.

High-strength structural steel used by the California Division of Highways in welded structures have been ASTM A242, weldable grade, and T-1 heat-treated alloy structural steel. Some of the major structures in which these steels have been designed are described below. All these structures have been or are being successfully fabricated and of those in place no major difficulties have developed. Because of the newness of some of the alloys and the variability of the many A242 steels, most fabricators seem to have difficulties during the establishment of welding procedures. However, once the procedures are qualified and then followed during fabrication, few if any problems have been encountered. On only one structure has extensive major defects occurred during the actual fabrication. This was a series of transverse and longitudinal cracking in fillet welds placed by the automatic process. These defects were traced to workmanship not anticipated during establishment of the welding procedure. The defects were repaired and recently were inspected after being in service for approximately two years. The inspection revealed the repaired welds and similar work, welded properly originally, to be in good condition and functioning as designed.

At the risk of alienating those who believe that inspection of welding is unnecessary, this paper will emphasize the quality control of welding of low-alloy steels rather than outline specific processes used. These views reflect the experience of the authors that there is an infinite number of procedures to follow in welding any material, but that once a procedure is established then it must be followed within the established tolerances or problems will develop. The following discussion also reflects the authors' experiences in that most of the points covered are those that have been observed to give trouble during actual fabrication.

Examples of Bridge Construction Using Alloy Steels

Carquinez Bridge

The lead photograph shows the parallel bridges across the Carquinez Straits approximately 25 miles north of San Francisco. The new bridge (right) is a double-cantilever structure with two 1100-ft main spans. It parallels an older structure on the upstream side and was designed to have the same general appearance and spans as the old for esthetic reasons. This bridge is all-welded construction with bolted field connections.

Fig. 1—South Fork of Eel River Bridge at Dyerville, Calif.; erected in 1958

Fig. 2—Huasna River Bridge; erected in 1958

Fig. 3—Benicia-Martinez Bridge

Approximately 3000 tons of T-1 steel were used in the Carquinez Bridge trusses for the heavily stressed members, 5000 tons of A242 steel were used for intermediate stressed members, and 6000 tons of A373 steel were used for lightly stressed members.

By use of alloy steels and welding, a saving of about $800,000 was realized in the cost of the superstructure, according to figures supplied by the designers.

The interchange and approaches which can be seen in the foreground leading to the new and old bridge are also all-welded construction plate girder design, using A242 manganese-vanadium type steels.

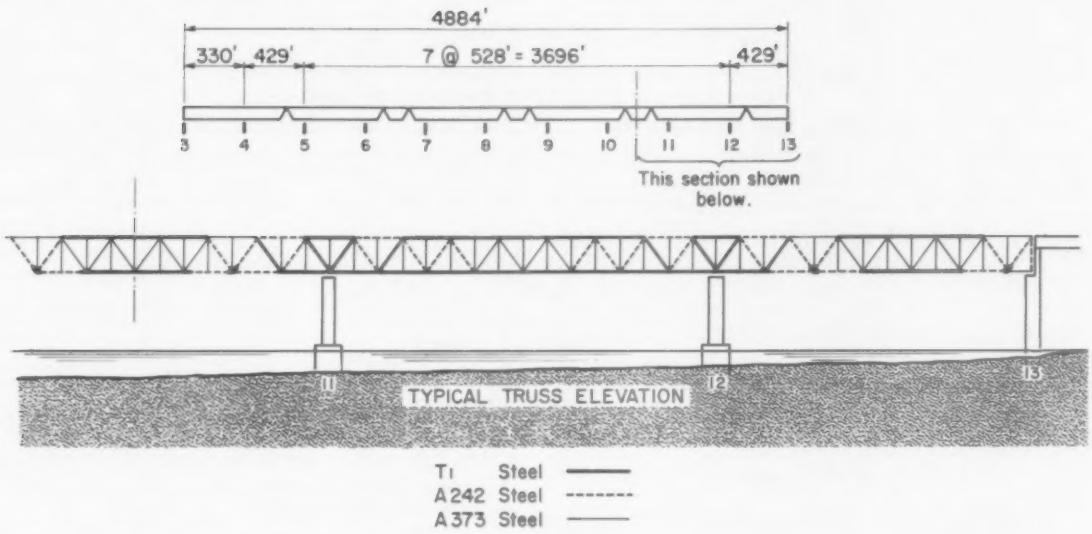


Fig. 4—Diagram showing types of steel used in Benicia-Martinez Bridge

This structure has been in service for approximately two years.

Two other bridges were fabricated and erected in 1958 employing low-alloy A242 steel and welding. One was the South Fork of the Eel River Bridge (Fig. 1) at Dyerville, Calif. Spans ranged in length from 110 to 170 ft., using haunched girder for the middle span. Flanges for these girders were A242 steel and web plates were of A373 steel. Approximately 1200 tons of steel went into this bridge.

The other was the Huasna River Bridge (Fig. 2). This was a plate-girder bridge of 9 spans. The spans were 160 to 170 ft long. The girder depth was 10 ft. Approximately 1160 tons of A242 steel were used in this bridge.

Benicia-Martinez Bridge

The Benicia-Martinez Bridge, which will span the Carquinez Strait about 4 miles upstream from the Carquinez Bridge, is now under construction. This bridge, shown in Fig. 3, will parallel an existing railroad bridge. The bridge is made up of truss spans ranging from 330 ft up to 528 ft in length. Here the designer also used three types of steel, T-1, A242 and A373, in order to economically carry a uniform depth of truss across the bridge without the necessity of deepening over the piers.

Figure 4 shows the location of the three types of steel, T-1, A242 and A373, in the Benicia-Martinez Structure. Like the Carquinez Bridge it will be welded construction with bolted field connections.

Whiseky Creek

The Whiskey Creek Bridge, now under construction in northern California, is a good example of the new design approach in plate-girder spans made possible by welding. In this case T-1, A242 and A373 steels have been welded together (Fig. 5) so that flanges and webs are T-1 steel at the high-stress regions welded to A242 steel at the intermediate-stress regions, and A373 steel at the low-stress regions. This provides economic use of plate girders over a 350-ft span and permits the use of a beam with a constant depth of 12 ft and has a flange with a constant thickness of $1^3/_4$ in., except for a 90-ft section in the center of the long span, which has 2-in. flanges. However, this increase in flange thickness is placed to the outside of the flange so that the web fillet weld is straight for the full 290-ft length of the girders, thus simplifying fabrication of the girders. The flange width is uniform.

Uniform-depth plate girders have basically the same geometric configuration from contract to contract so that the plate-girder fabrication line in the various fabrication shops needs little changing to adapt it to the length and width of plate girders for the various contracts. This simplifies fabrication and cuts costs, so that broader competition is invited and fabricators are encouraged to make use of the advances in welding knowledge, processes and experience gained over the past years.

Terminal Island Bridge

A structure presently being designed, utilizing A242 steel, spans the Los Angeles Harbor in San Pedro to reach Terminal Island. The present design of the bridge is a cable-suspension bridge utilizing approximately 10,500 tons of welded structural steel. This includes 900 tons of A242 welded structural steel. Like the Carquinez Bridge, the Terminal Island Bridge will be of welded construction with bolted field connections. A special consideration during the design of this structure was whether or not the towers could be fabricated by welding to the tolerances needed. This was resolved in the favor of welded fabrication.

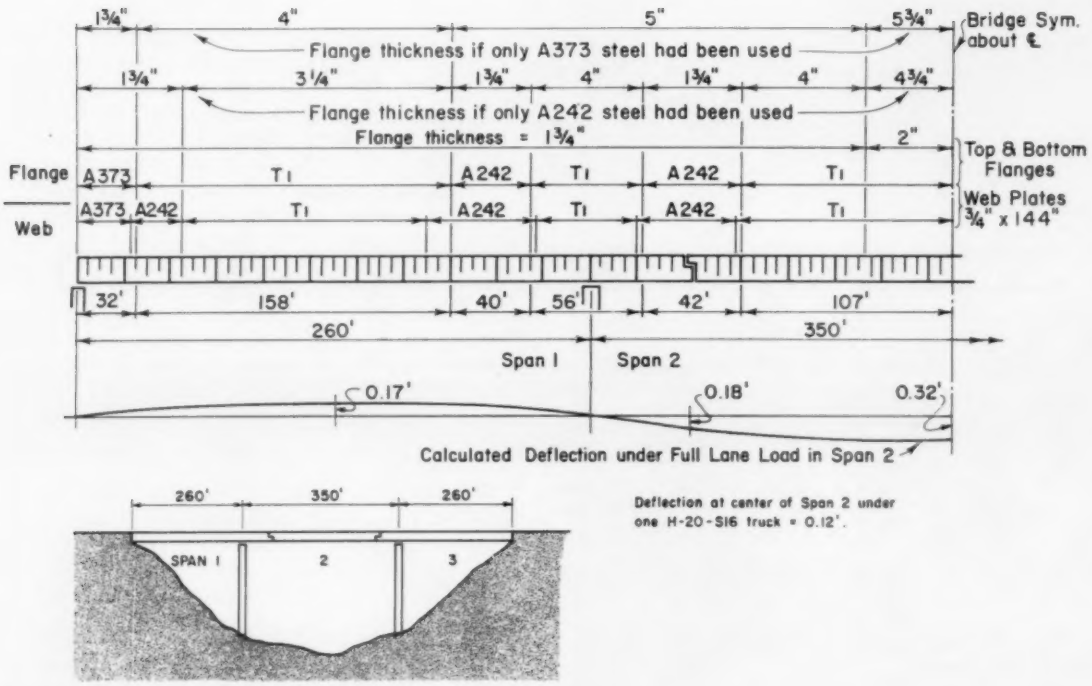


Fig. 5—Diagram showing types of steel used in Whiskey Creek Bridge

Supervision

A lack of understanding that there is a difference between the tolerable deviations in welding low-carbon structural steels and welding low-alloy steels has probably caused more difficulties than any one other factor. Mill producers have a tendency to describe low-alloy steels as being "weldable" or of "excellent welding quality." These words seem to be interpreted as "easy to weld." Actually the words primarily are used to describe the material as having good metallurgical qualities after being properly welded rather than to describe a degree of difficulty. It must be kept in mind that low-alloy steels are harder to weld than are low-carbon steels primarily because greater care must be exercised throughout the entire fabrication process.

When welding low-alloy high-tensile steel, the management of the fabrication shop must impress upon all persons working on the particular project—especially the welder—that the type of steel and welding procedures they must use are more critical than for normal bridge fabrication. In many large fabrication shops, where many components are being fabricated for a project or projects, the shop superintendent or the welders, or both, have been observed to lose track of what electrode to use and where. This is especially true where a shop that has been fabricating only with A7 or A373 structural steel, has contracted to fabricate a welded structure containing low-alloy high-tensile steel.

For this reason, an inspector is required to be more careful in taking test samples and checking periodically to insure the use of appropriate welding materials. It is also necessary that he check the con-

Fig. 6—Proposed Terminal Island Bridge in Los Angeles

trol of welding procedures closely so that the work will result in a smooth, correctly shaped weld, and thus reduce the possibility of incurring such crack starters as overlay, undercutting, slag inclusions and crater cracking. To facilitate this control, the California Division of Highways has established minimum standards of mechanical performance which welds of different types must meet in order to satisfy design requirements and assure the use of good welding techniques. Thus various test welds are required of welders and welding procedures before they may be used on highway contracts, in order to demonstrate the reliability of the welder or procedure in question.

There seems to be some misunderstanding as to the reasons for the concern of the owner over the degree of welding quality. Some advocates of welding seem to think that if welding errors occur, they will be covered by the factor of safety. This indicates a misunderstanding of the function of the safety factor. The designer bases his quantitative work with the material on allowable design stress. The margin between maximum stress and strain and the failure stress and ductility of the structural material constitutes the commonly measured safety factor. Thus, while the factor of safety is expressed quantitatively, it is actually determined by the quality of the material and its fabrication.

The necessary size of this safety margin has been determined by investigations based on service experience in the industry, and it includes protection against unforeseen loading conditions, unknowns in design theory, standard tolerances in fabrication practice, and, in welded design, a reasonable number and type of welding defects.

It is this last element that seems to be most misunderstood, in that little research has been done concerning the effect of defects in a highway bridge. For instance, the tolerance of cracks in weld or base metal probably is zero while a certain amount of most any other defect obviously can be tolerated.

The mechanical and chemical requirements listed in the present A242 weldable low-alloy structural-steel specifications include practically none of the metallurgical factors which must be considered when estimating the reliability of a structural weldment. The influence of the unspecified factors is large enough to cause the reliability or probability of failure to vary considerably. While this example is on the dramatic side, the influence of unspecified metallurgical factors was well demonstrated by the numerous welded ship failures incurred during World War II.

Therefore, in the absence of any quantitative information concerning the effects of various combinations of welding procedures and metallurgical characteristics on the structural reliability of the material, it is necessary to establish weld-quality requirements and tests to measure the critical factors.

Bridge designs are based on weldments having at least the median of metallurgical quality that can be produced by a skilled welder, using good equipment and recommended procedures. Tests normally are based on the average work of this highly skilled mechanic rather than on merely the work of the average welder.

The weld tests and performance minimums required by the State of California are based on the above philosophy and are set forth in the current California Test Method 601 and the AWS Specification D2.0-56. In addition to standard tests, this method includes the California Keyhole "T" Bend Test[1] for fillet welding. This test method also outlines inspection, sampling, and testing techniques, and prescribes the use, limits and standards of nondestructive testing. For instance, the radiographic standards in the Test Method 601 are diagrammed for practical application to the interpretation of radiographs, etc.

Welding of Low-alloy Structural Steel

As in the welding of any steel, it is necessary for the welding expert to mechanically match his electrodes or wire and flux combination to the type of low-alloy steel to be used while, at the same time, considering all metallurgical affects of the combinations.

This first step preparatory to the trial and error refinement process of procedure tests is the same for welding all materials. However, once procedures are established for low-alloy structural steels, then they must be held to closer limits than are normally applied to low-carbon structural steels. This also applies to standards and practices of workmanship.

The higher standards needed during the fabrication of the low alloys are due to the greater sensitivity of such steels to many factors. So as to better explain and illustrate this fact, several specific examples will be used to point out the differences.

For instance, tack welding and welding of clips or "dogs" for fabrication must be well controlled. There have been cases in which a clip welded to a flange or web has started a crack which propagated into the base metal. In one case, after these clips were burned off and the surfaces ground smooth, cracks in the base metal remained and were not dejected until just prior to erection. If this type of crack should be allowed to remain, it would propagate in service and lead to a failure.

In order to perform trouble-free fillet welding by the automatic process, all mill scale should be re-

Fig. 7—Low-alloy steel flange

Fig. 8—Fillet-weld overlay

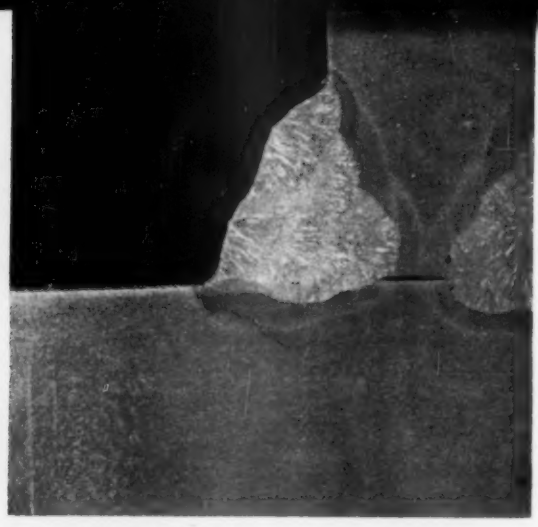


Fig. 9—Fillet-weld toe crack

moved from the area to be welded. This is especially true of low-alloy steel. Figure 7 shows an alloy-steel flange that has been ground in the center so as to avoid incurring overlay or lack of fusion due to the presence of mill scale. Welding web-alignment clips to an alloy-steel flange, as shown here, in order to simplify jigging is poor practice. Transverse cracks in the flange often occur beneath such clip welds.

Figure 8 is a macrograph of the toe of a fillet weld showing the consequences of placing a fillet weld over heavy mill scale. As may be noticed, the oxide has not been washed out by the flux, and consequently it has prevented the weld metal from wetting the plate beneath. The sharp re-entrant created is a very likely place for longitudinal cracking to start. This type of overlay defect is often invisible to the eye as the mill scale completely fills the opening.

The proper starting of the arc is of utmost importance in welding low-alloy structural steel. Some welders have the bad habit of striking the arc away from the weld area or groove and dragging the arc into the weld area to continue. The welding arc should never be started outside the weld area on low-alloy high-strength steel. When the arc is struck outside the weld area and dragged into the weld groove, it leaves a trail of small arc pits which consist of small blobs of deposited weld metal (quenched metal) embedded into the surface of the steel. These are created as the arc strikes and breaks contact on the steel intermittently without the benefit of proper flux or gas-shield cover. These minute puddles of molten metal, caused by the arc striking or dragging, are quenched instantly by the mass of cold metal under them. Simultaneously the lack of surface protection permits these puddles to absorb nitrogen from the air. Thus, these quenched puddles become small particles of extremely hard material which provide biaxial restraint at the interface between the particles and the base metal. This results in a sharp stress increase which may initiate a crack.

It should be stressed to the welding personnel that better than average welding should be maintained for alloy fillet welding. If the toe of the fillet weld is not

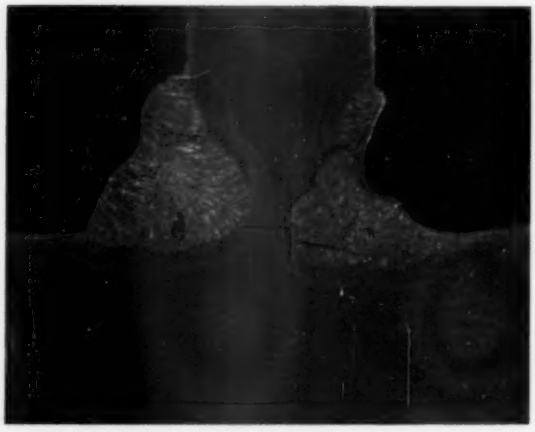


Fig. 10—Fillet-weld longitudinal crack along fusion line

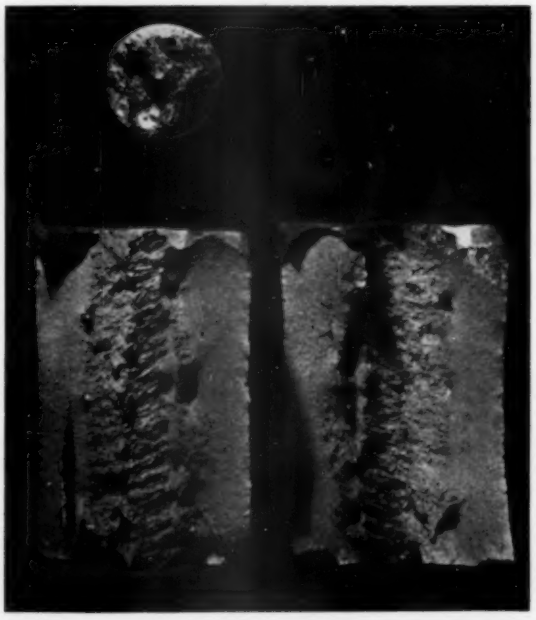


Fig. 11—Tensile fracture specimens

feathered or faired into the base metal properly, cracking is likely to occur at that point due to the weld-metal shrinkage.

Figure 9 illustrates a crack in the base metal at the toe of the fillet. This is the consequence of using poor welding technique. The sharp angled toe of this fillet weld has provided sufficient concentration of the stresses caused by the cooling of the massive fillet section to result in the failure of the alloy-steel base metal.

This same type of crack can occur whenever submerged-arc fillet welds are made on low-alloy high-strength steels even though the process may be metallurgically and mechanically correct. The penetration, dilution and cooling rate are such that in most cases adequate strength and a gain in ductility may be obtained by using a low-carbon wire with appropriate flux combinations which would nominally provide tensile strengths lower than the base metal. Ductility relieves the tendency to crack.

Properly controlled low-hydrogen welding processes should be used on low-alloy high-strength steel so as to eliminate hydrogen from the weldment.

To insure this, it may be necessary to bake the low-hydrogen electrodes between (500 to 800° F) or as specified by the electrode manufacturer so as to remove excess moisture from the covering. Electrodes after baking or removal from hermetically sealed containers should be stored in a holding oven of about 250° F and maintained at this temperature until used. The electrode should be taken from the oven and used only as needed.

When using submerged-arc welding processes, the welding-flux material must also be moisture controlled.

Figure 10 shows a longitudinal crack along the fusion line of a submerged-arc fillet weld. This could have been induced by thermal contraction stresses in the weld but probably was the result of moisture in the flux. As a matter of interest, during a special investigation, this type of cracking and also transverse cracking were most easily reproduced by excess moisture in the flux. The irregular fillet contour on the right is due to a compressed-air carbon-arc scarfing operation.

Preheat requirements for T-1 steel vary from 200 to 400° F. Sufficient impact strength in and adjacent to T-1 weldments is preserved if weld-heat inputs are selected to correspond to the limits as prescribed by the manufacturers of this type of steel. These preheat and heat-input limitations, while not theoretically applicable, are, nonetheless, practical for welding on the other high-strength low-alloy structural steels such as the ASTM A242 grades. However, certain limitations are imposed on the welding procedures by the geometry and chemistry of the base metal. Thus, the preservation of sound weld metal which is tough enough to pass procedure tests may require a further reduction of arc heat input, so as to reduce the "arc power" or heat-input rate per inch of weld—in order to prevent a temperature buildup in the puddle.

Often fabricators, in order to avoid back scarfing, will submit a butt-welding procedure on heavy joints, in which root penetration has been secured by making root passes at high-amperage levels. The apparent penetration and tensile strength are satisfactory in such cases but toughness, fatigue and impact strengths drop sharply because of the poor metal structure produced by this practice. Figure 11 shows a tensile fracture section of a joint so prepared. The coarse dendritic structure and the intergranular fracture at the root passes, as opposed to the rest of the weld which was made at normal-amperage levels, should be noted. The poor ductility of these root passes is shown by the lack of area reduction apparent in the end view (shown in Fig. 11, above left) of the tensile specimen taken from the root-pass area. Moreover, such weld-metal structures are very susceptible to high-temperature shrinkage cracking. Unfortunately, these cracks are not easily detected with the conventional nondestructive-testing methods and so must be controlled by correct procedure.

It has been local experience that, for alloy steels, a back scarf made using the carbon-arc compressed-air process is more satisfactory than when made by the oxyacetylene process. This may be due to the fact that the heated metal is localized in a smaller area by the carbon arc than when using an oxyacetylene torch.

Closure

Commendation has been earned by the AWS D2.0 Welded Bridge Committee for their promotion of improved methods for testing and qualifying welders and welding procedures as an adjunct to the development of quality-control specifications for welding low-carbon structural steels.

The Bridge Committee has also studied the weldability of various ASTM A242 steels as a preliminary to projecting their specifications into the use of high-strength low-alloy structural steels with the result that such steels will soon be included. This work also included discussions with the ASTM Committee on the needs of the welding industry in so far as definite chemical-composition limits for a weldable low-alloy steel of intermediate strength is concerned. As a result of this study, it is understood that the ASTM will soon issue a tentative specification for a manganese-vanadium steel to serve this purpose. It is suggested that, as soon as this new steel specification is available, the welding industry should thoroughly study its application to the weldability of the steel and report their findings to the AWS D2.0 Committee.

References

1. Beaton, J. L., Jonas, P. G., and Kendrick, C. B., "Fillet Weld Keyhole "T" Bend Test," presented to Highway Research Board 39th Annual Meeting, Washington, D. C.
2. Elliott, A. L., "New Horizons for High-Strength Steels," presented to AISC Denver Meeting, May 6, 1960. (*Note:* Diagrams of Benicia-Martinez and Whiskey Creek Bridges used in this paper were originally prepared for the AISC meeting.)
3. Hollister, L. C., and Sunbury, R. D., "High-Strength Steels Show Economy for Bridges," *Civil Eng.*, **30**, No. 6 (June 1960).

Fig. 1—Phillpotts Dam, Va.; example of remote area of job sites of hydroelectric repair work

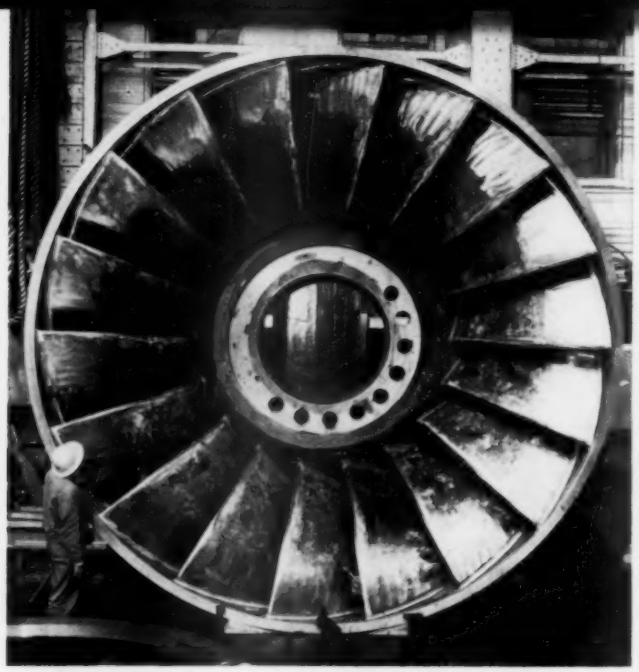


Fig 2—Francis-type runner showing stainless-steel inlay on outer third of blade. This is a factory inlay job, not in place at the dam. This is the largest runner in the U.S. at present; it will go into Niagara Falls Power House. Weight 150,000 lb; 250,000 hp. Picture from Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

Welding Repairs

of Cavitation on Large Hydroelectric Turbines

require careful consideration of the various steps involved in weld preparation, deposition technique and finishing

BY MARTIN FRIEDMANN, JR.

SYNOPSIS. Cavitation conditions in hydroelectric turbines lead to pitting in the runners and can cause major damage. When the degree of pitting becomes excessive, repair is in order. This article attempts to discuss some of the problems encountered in the repair of these turbines in place at the dam site without dismantling the turbine. Also, it gives general procedure directions in overcoming not only the actual welding problems, but those encountered in selecting and maintaining equipment used on the job, and the various steps involved in weld preparation, welding and finishing.

Introduction

There are two types of wheels on which most inlay and repair work is done. These are: Francis and Kaplan. The Francis has a band around the outer edge and is nonadjustable in pitch (see Fig. 2). The Kaplan is similar to an electric fan with short stubby blades which are adjustable in pitch (see Fig. 3). Repairing of the damaged runners is done in three steps:

1. Weld preparation
2. Welding
3. Finishing to contour

Each step must be done in a meticulous manner in order to preserve the original contour in the finished repaired blade.

Weld Preparation

Weld preparation involves the removal of the base metal in the pitted area. This is accomplished either by gouging by carbon arc, using compressed air to blow away the slag, or by chipping and some grinding. Each method has its advantages and disadvantages. Carbon-arc gouging is faster but requires greater control on the part of the operator to prevent warpage. Also, it can be uncomfortable, even dangerous, to the operator, who, working in restricted places, often gets burned by the hot metal blown away.

MARTIN FRIEDMANN, JR., Owner, Martin Friedmann Co., South Norfolk, Va.

Paper presented at AWS 1960 National Fall Meeting held at the Hotel Penn-Sheraton, Pittsburgh, Pa., Sept. 26–29, 1960.

Fig. 3—Kaplan-type runner at Roanoke Rapids, N. C. Repaired in 1958 for Virginia Electric & Power Co. in position. Note amount of overhead work

Chipping and Grinding

Chipping and grinding are more easily controlled by the operator to insure removal of the proper amount of base metal without distortion of the blade. Therefore, chipping is used more often and will be the method discussed in this article.

Before the actual chipping is done, a paper template is made showing the outline of the area to be inlaid. (This template is also used as the basis of payment for the job; its area is measured and any changes to the original outline are recorded.) Then the metal is removed to a depth of $^1/_8$ to $^3/_{16}$ in., all around the edges. Next a series of grooves of the same depth, and about $^1/_2$ to $^3/_4$ in. apart, is run all through the outlined area. After checking the depth of these grooves, the metal between them is cut away. This method insures uniform depth in removal of the base metal and helps preserve the original contour of the blade.

In this part of the work, No. 2 air-chipping guns with specially tempered steel chisels have been very satisfactory. Some places which are inaccessible to the chipping hammer must be ground out with nose wheels on 24–36-in. long grinders.

On a repair job of this type it is advisable to take about 50% more air tools than estimated necessary because a breakdown of this equipment, in the remote job sites where this work is usually done, can be quite serious for the contractor.

Welding

Welding is done in almost the same sequence as the chipping. A series of beads is run in a pattern $^1/_2$ to $^3/_4$ in. apart, usually two high. These are checked for height and then the spaces between them are filled. This procedure is followed to assure uniform deposit of weld metal, with no high

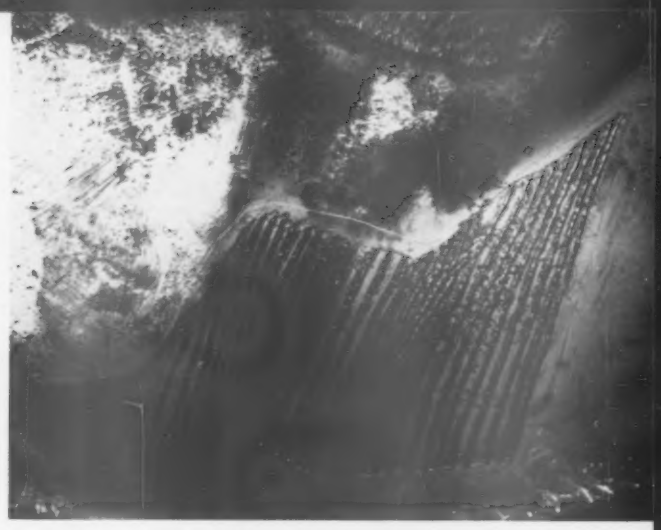


Fig. 4—Kaplan blade, 55,000 hp: old inlay at bottom edge is still good; center shows welding in progress; finished weld before grinding is shown at top

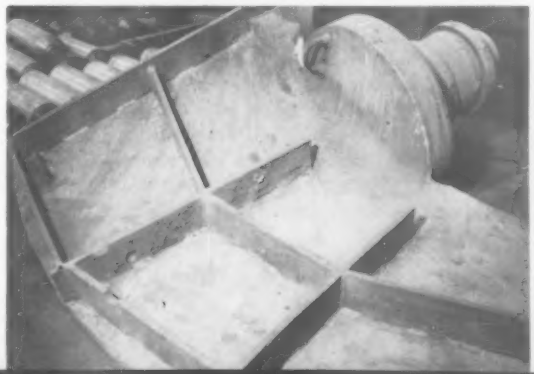
or low spots. The middle of Fig. 4 shows welding in progress; the top shows finished weld before polishing; and the bottom edge shows inlay done three years before present repair work.

If pitting is over $^1/_4$ in. deep, inlay is made of mild steel to rough contour, then finished with stainless steel. Sometimes deep fissures and cracks are exposed and some welds can be as much as 3 or 4 in. deep. In welding these cracks, extreme care must be taken to prevent warping the blade.

When welding on a turbine blade it is desirable to weld in such a direction as to take advantage of the stiffness given it by the curvature of the blade. This is comparatively simple in a Francis-type wheel, but a Kaplan-type has only a slight curve in its blade; thus, advantage must be taken of whatever slight curves can be found. Thorough peening, skip welding and, in extreme cases, resorting to heat preloaded strong backs usually minimize warpage. Figure 5 shows a runner with strong backs in place to control warpage.

These preloaded strong backs can be 1 x 6 in. hot-rolled flat bar set edgewise on the side of the blade opposite to the welded surface. These bars are set in the pattern dictated by the contour of the inlay. First, one end is welded; then the bar is heated to expand it the required amount; and, next, the other end is welded. This continues until the blade is prestressed enough to counteract the warping action from the inlay. After the inlay has been completed and rough ground, the backup straps are removed and the spots where they were welded are smoothened with the grinder.

Fig. 5—Strong backs on blade are used to prevent warpage



Francis-type wheels are easier to repair without warpage than are Kaplan type. The Kaplan-type wheels must be strictly controlled as to sequence and amount of welding. Exact formulas are not possible as each wheel presents its own unique problems.

Types of Welding Electrode

Type 308 or 301 stainless steel is the filler metal usually specified for inlay. A $^3/_{16}$-in. electrode is used for most of the inlay except for very difficult places and for touch-up work, where $^5/_{32}$- and $^1/_8$-in electrodes are used. A lime-coated electrode is preferred to the heavy-slag type because it leaves fewer pockets in the inlay to show up in the finished surface. The gas and oxides entrapped in the cast-steel blades are not easily washed out by the welder with heavy-slag electrodes.

Inert-gas-shielded metal-arc welding has been tried but, for three reasons, has not been successfully used in turbine-blade repairs in position:

1. The inability of the operator to manipulate the gas metal-arc torch in confined quarters.
2. The high heat input into the blades increases the amount of warpage.
3. The speed of gas metal-arc welding and the quick solidification of the weld metal do not give entrapped gas and oxides a chance to dissipate; this may leave many voids in the finished surface.

Heavy Equipment for Welding

Direct-current motor generators should be used for arc welding. Some welders have had bad experiences with shock from the high open-circuit voltages on a-c machines. Men are sweaty, humidity is high, and the welder usually works with his shoulders wedged against the blade in back of him. Sometimes 32-v light circuits are specified. Electric grinders and sanders should not be used for the same reasons. The air grinders are more compact and stand up under the heavy grinding pressures used.

Welders and Equipment

The actual welding is done by a trained crew of welders all of whom have passed the AWS tests in vertical, horizontal and overhead positions. Approximately 85% of all the welding is done in the overhead and vertical positions. The welders must be highly skilled in depositing, as nearly as possible, the correct amount of stainless-steel filler metal—just enough, not too much—since stainless steel is quite difficult to grind, especially when 100 ft or more under a dam and working while wedged between the blades.

Full leather clothes for protection are a "must." Also, protective glasses must be worn, under hoods because hot slag popping off the weld beads when cooling or when being peened is dangerous in such close quarters. Short stubby insulated electrode holders and extra flexible leads are also essential.

Care of Welding Electrodes

Welding electrodes are stored in sealed boxes, and a day's supply of electrodes is drawn from a hot box thermostatically controlled to 150° F. The high humidity of the job site makes this precaution necessary to keep electrodes in usable condition while being stored on the job.

Testing for Depth of Inlay

One of the problems on an inlay job is a quick means of checking the depth of the finished deposit. A number of magnetic flux meters, made both here and abroad, can be used for this purpose. However, they are quite expensive and it is economically impractical to furnish each welder with one of them. A small pencil with a very powerful Alnico magnet in the tip has been found useful for this purpose—it is easily carried by each welder, it is inexpensive, and is not cumbersome. The magnet is of such strength that if the inlay is over $^1/_8$ in. thick, it will not stick; at $^3/_{16}$ in. thickness of inlay over the steel blade, the pull is just barely preceptible. At less than $^5/_{16}$ in., the magnetic pull is strong enough to almost support the weight of the pencil. This small tool, then, makes possible a quick field test of inlay depth by each welder.

Finishing to Contour

This is the final step in repairs of the damaged impeller. All the approved welded inlay is ground to a bright finish in the original contour of the blade. The operator must be careful not to remove too much metal.

The grinders vary in size from small grinders using mounted wheels turning up to 24,000 rpm, to 6- to 8-in wheel grinders. Some grinders have extended handles making them 3 to 4 ft long. There are also offset grinders of various types.

Resinoid-bonded wheels are the only type which can give efficient service under the rough conditions and speed with which they work. The grit varies from 16 to 60 plus, hardness should be at least P or Q. Seven or 9 in diam. $^1/_4$-in. thick solid disk sanders are also used.

Grinding wheels using glass cloth laminates should be avoided. These are highly irritating to the operator who may develop a bad rash within two or three days.

The wheel should be selected according to its use, whether used for rough grinding or for finish grinding. A wheel that is too hard will glaze and cut down on production and a too-soft wheel will wear down too quickly. One should avoid contaminating the stainless-steel inlay with metal from the adjacent cast steel.

The air tools used in both the preparation for welding and the finishing operation are connected to a header with a cluster of valves. This header, in turn, is connected to a 2-in. rubber hose which runs down to the work platform from the compressor. Lights are rigged the same way. A main line is brought down and plug-ins using short cords are used as needed.

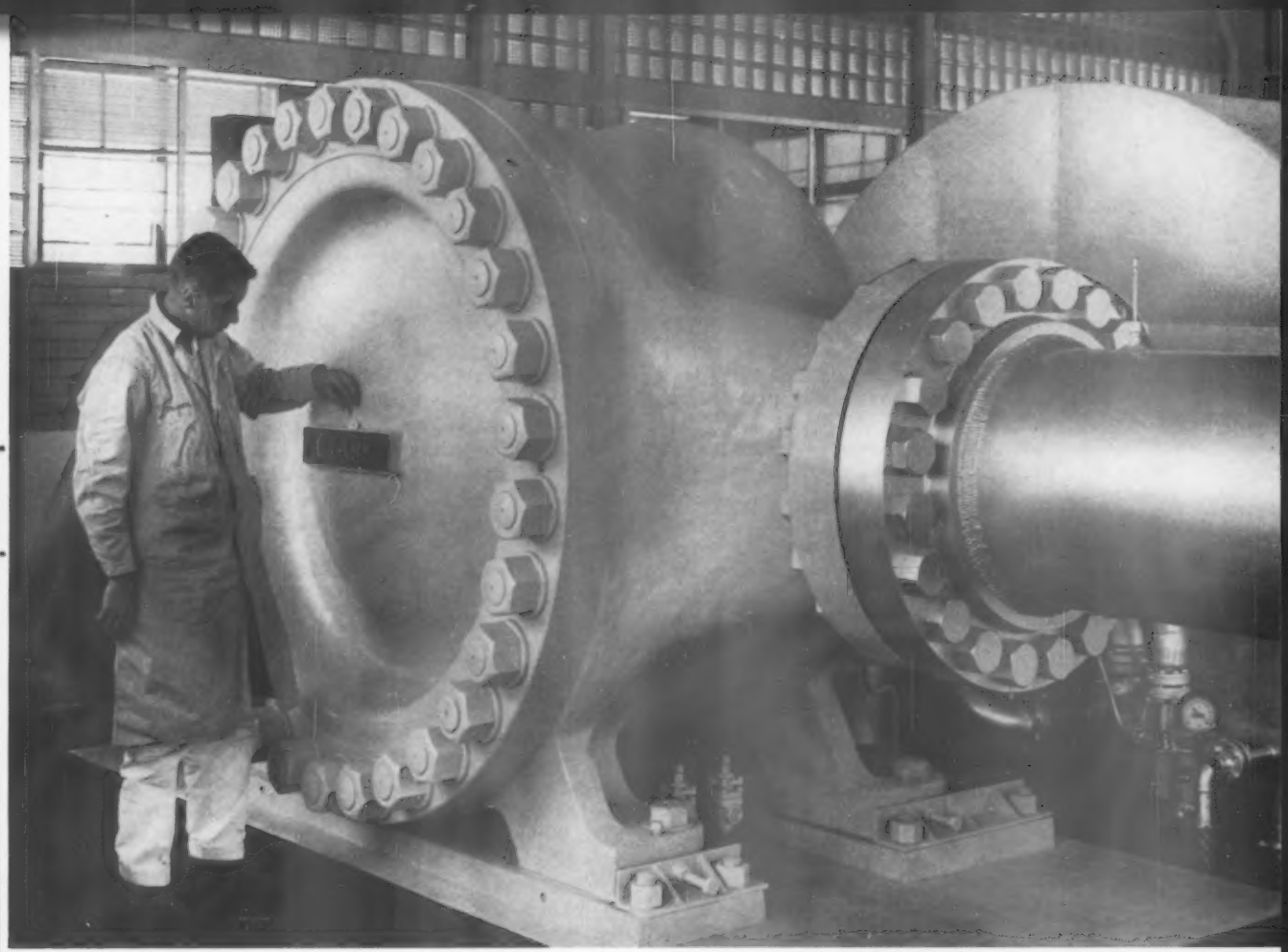


Fig. 1—A centrifugal compressor used for gas transmission on a 24-in. pipe line

Sufficient operator training and proper tool and equipment design are required for

Welding Centrifugal-Compressor Impeller Wheels

BY J. H. MATHENY AND E. L. AUL

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Paper presented at the 1960 National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

Introduction

Impeller wheels, as described in this paper, are used in centrifugal compressors in the gas-transmission field. The particular equipment for which these impellers were made is used in a 24-in. gas-transmission line and is shown in Fig. 1. The relative size of the impeller to the rest of the equipment is shown in Fig. 2.

Originally, this equipment was supplied with a 36-in. diam impeller of milled and riveted construc-

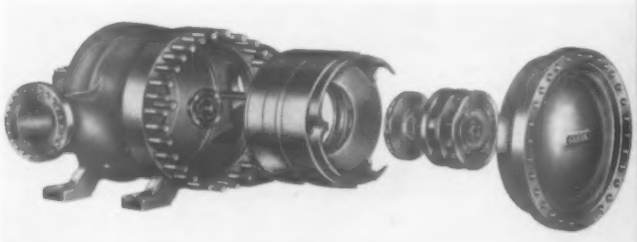

Fig. 2—Component parts of a centrifugal compressor showing the relative size of the impeller wheel

tion. The disk was made from an alloy-steel forging, varying in thickness from $1^1/_2$ in. at the outside diameter to 6 in. thickness at the center hub. From this forging, 18 vanes, or blades, were made by milling away the material between the blades, leaving integral blades with dimensions of $^1/_4$ in. thickness, $1^1/_2$ in. high near the hub diameter and extending radially 24 in. to the outside perimeter, where they were 1 in. high. A similar forging was used for the cover which was machined to fit the blade-edge configuration.

To rivet the above components together, rivet holes were drilled through the center of the protruding blade, on 1-in. centers. Next, the cover was placed on the disk in its relative position and the rivet holes were transfer drilled through the cover. The parts were then countersunk and riveted, and the outside surfaces were machined flush. After dynamic balancing, each assembly was oversped 15% above designed operating speed.

In the installations where these impellers were being used, it was desired to increase the volume of gas handled without resorting to major design changes of the existing impellers. It was therefore decided to fabricate the impeller using the same basic design and joining the parts by welding. This would enable the compressor to handle more volume and higher discharge pressures, by virtue of higher permissible operating speeds for welded impellers of a comparable design.

Materials

The service requirements of these parts dictated the need for one of the high-strength alloys which possess the necessary mechanical properties and still are readily fabricated with the plant's existing or modified facilities. In view of the satisfactory service given in mechanically joined impellers made from SAE 4340 steel, it was decided to use the same material for this program.

Both the cover and disk were made from open-die forgings which were modified slightly in configuration to allow additional stock for subsequent machining to compensate for anticipated distortion.

Both blades and impeller were of 4340 analysis with maximum limit of 0.015% on the phosphorus and sulfur contents. The blades were annealed sheet. The analysis of the impeller and cover material is shown in Table 1. The blade analysis was almost identical.

Procurement of a filler material with analysis and properties compatible to the base metals was more difficult than obtaining satisfactory base material. From the literature[1] it was anticipated that hot-short cracking would be encountered unless phosphorus and sulfur were controlled within acceptable levels. It was indicated by the welding-material suppliers that such precise control of these two elements was possible only by the vacuum-melting process. With the small quantities required for this program, the cost to have the material made to order would be prohibitive. After an exhaustive search, four materials were obtained with the analysis shown in Table 1.

Joint Design

In most welded impeller-wheel designs, there is no particular problem in selecting a joint design which will assure sound welds as, in most instances, the joints are readily accessible. However, in this design, there was only 1 in. clearance at the blade tip between cover and disk and the length and curvature of the blade necessitated a good portion of the welding being accomplished blind.

The first approach to select a satisfactory joint design was to try designs used by other manufacturers on similar parts. One design is to use a beveled slot which is milled through the cover and then weld through the slot to the edge of the blade which would be previously welded or milled as an integral part of the disk. Initial attempts to use this type joint indicated that it would be difficult to control the drop-through uniformly to avoid notches. This is shown in the sample, Fig. 3. Attempts were made to develop techniques to overcome this by using gas backing with the inert-gas process, copper backing bars, etc., all of which were unsatisfactory. The best method

Table 1—Loss of Elements in Gas Metal-arc Welding Using 1 and 5% Oxygen-argon Gas

Base-metal composition		Filler Material Composition and Resultant Change											
		I			II			III			IV		
		A[a]	B	C	A	B	C	A	B	C	A	B	C
Carbon	0.41	0.30	0.20	0.20	0.25	0.20	0.20	0.30	0.27	0.27	0.21	0.22	0.20
Manganese	0.76	0.55	0.62	0.56	0.50	0.59	0.56	0.80	0.77	0.65	0.80	0.68	0.65
Phosphorus	0.012	0.016	...	...	0.011	...	...	0.020	...	...	0.025	...	...
Sulfur	0.015	0.019	...	...	0.002	...	...	0.020	...	...	0.025	...	...
Silicon	0.32	0.65	...	...	0.70	...	...	0.30	...	...	0.28	...	...
Nickel	1.83	...	...	...	...	...	...	...	...	...	0.55	0.61	0.69
Chromium	0.80	1.25	1.31	1.24	1.25	1.30	1.22	1.00	0.96	0.92	0.50	0.50	0.51
Moly	0.26	0.50	0.48	0.53	0.50	0.48	0.47	...	...	...	0.20	0.20	0.20
Vanadium	...	0.25	0.23	0.24	0.25	0.25	0.22	0.20	0.18	0.18	...	...	...

[a] A—nominal filler material composition; B—weld-metal composition using 1% oxygen–99% argon mixture; C—weld-metal composition using 5% oxygen–95% argon mixture.

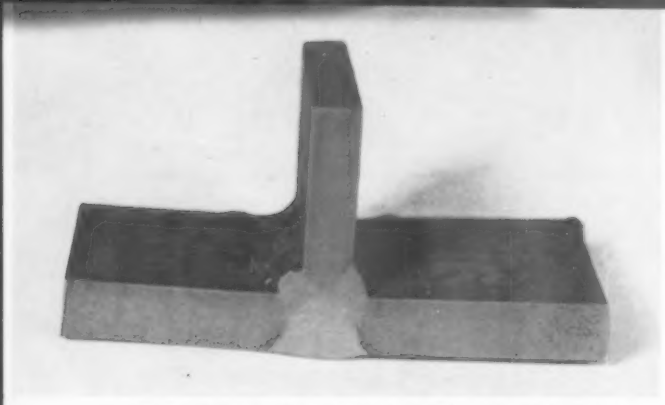

Fig. 3—Macrosection of a typical slot weld with irregular drop-through of the weld leaving sharp notches

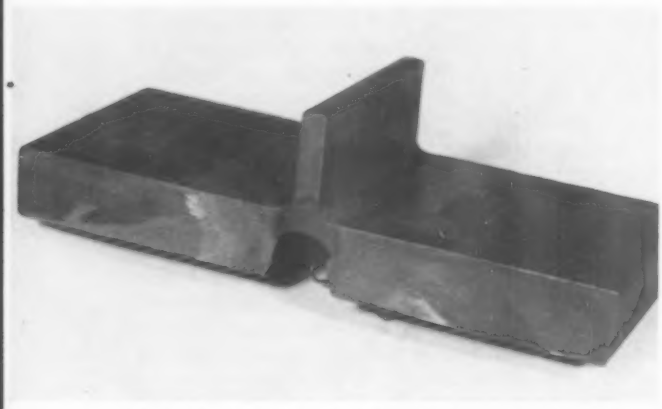

Fig. 4—Macrosection of a slot weld where underside or drop-through has been controlled using refractory backing

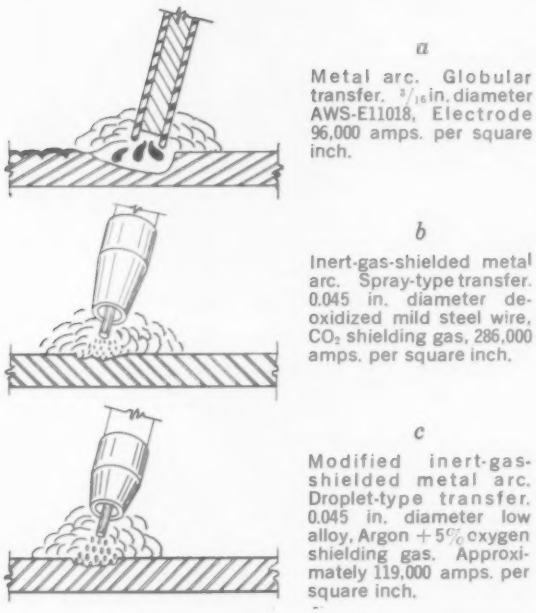
a
Metal arc. Globular transfer. 3/16 in. diameter AWS-E11018, Electrode 96,000 amps. per square inch.
b
Inert-gas-shielded metal arc. Spray-type transfer. 0.045 in. diameter deoxidized mild steel wire, CO_2 shielding gas, 286,000 amps. per square inch.
c
Modified inert-gas-shielded metal arc. Droplet-type transfer. 0.045 in. diameter low alloy, Argon + 5% oxygen shielding gas. Approximately 119,000 amps. per square inch.

Fig. 5—Illustration of the relative current densities for the welding processes considered for use on this program

developed was the use of a castable refractory which could be molded accurately to the blade contour and actually form the desired root-bead contour. The result of this development is shown in Fig. 4. This seemed to be the answer until full-sized samples were made. It was desirable to make both the disk and cover as uniform in thickness as possible to minimize and control distortion. This resulted in the cover being 3/4 in. thick at the outside diameter and tapered to approximately 1 1/2 in. near the center. With 18 slots of the required size, it was realized that distortion, cracking and other problems would be difficult, if not impossible, to control.

All further attempts to develop an unorthodox joint design were then abandoned. It was decided to make special welding equipment to weld the inaccessible areas and to use a standard double-bevel fillet weld to join the blade to the disk after the cover and blades had been welded. The blade preparation was to bevel 45 deg., 3/32 in. deep from both sides, leaving a 1/16-in. land in the center.

Welding Equipment

The selection of the welding process to be used was predicated basically on the assumption that the equipment of the process to be used could be modified to reach the inaccessible welds and still deposit a sound, uniform weld. No particular problem was anticipated in obtaining satisfactory mechanical properties with any of the processes.

Submerged-arc welding has been used on similar weldments, but it was not considered applicable in this instance because of space limitations for the welding nozzle and the addition of flux. Inert-gas-shielded metal-arc welding with tungsten electrode, which was used for all tack welding and in some areas on the blade ends, was not considered, again because of space limitations in welding the difficult or blind areas.

The shielded metal-arc welding process was explored quite extensively because of available equipment, trained operators and suitable welding alloys. For the most of this work, electrodes in the AWS E-00018 classification were used. This group was selected, first of all, for desired mechanical properties and, second, so that the drag-technique characteristics of these electrodes could be utilized for the blind welding. Special-length electrodes, bent to the blade curvature and then flux coated, were obtained and used for this work. Although it was possible to achieve normally acceptable welds with the above, the welds were not acceptable in this application because of excessive bead size, surface roughness and excessive spatter.

With the elimination of the other processes, the remaining process to explore was inert-gas-shielded metal-arc welding with consumable electrode. For this, a d-c rectifier constant-potential power source, with electronic controls and a wire drive unit, was selected. In addition to the standard equipment described, a reactor was added to the secondary of the welding equipment so that current densities could be reduced for better control of bead contour,

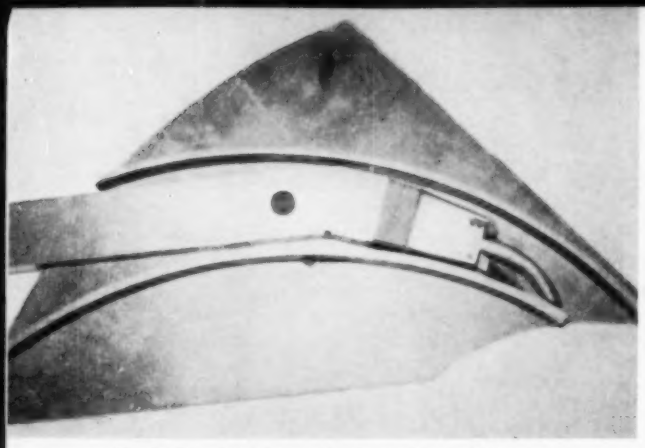

Fig. 6—Special designed torch used to weld the convex side of blades to the disk

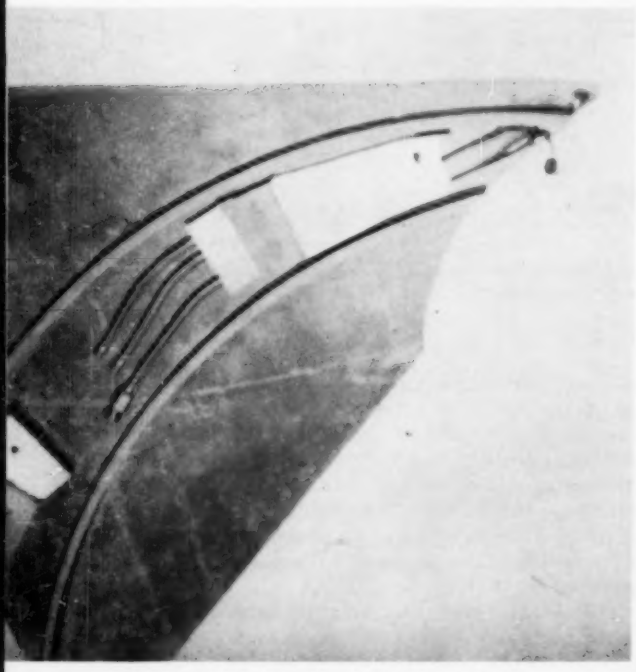

Fig. 7—Special designed torch used to weld the concave side of blade to the disk

less spatter and slower welding speeds. This can best be described by referring to Fig. 5 which describes the relative metal transfer of the processes considered. It will be noted that the metal transfer across the arc using the shielded metal-arc process is depicted as being globular and, inasmuch as the electrode could not be manipulated for proper angle, etc., a rough convex weld was obtained. In B, the typical spray-type metal transfer for the shielded-gas process with extremely high-current densities is shown. This was objectionable from the standpoint of excess weld deposit, bead shape, spatter and speeds which could not be controlled without expensive tooling. The droplet-type technique was selected for further development as it seemed to have all of the attributes to overcome the shortcomings of the other two processes. This was the process finally used on production parts.

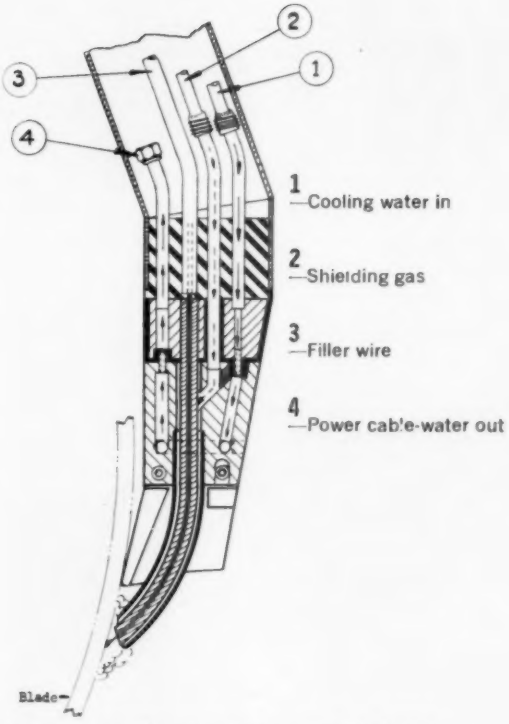

Fig. 8—Cross section of one of the special designed torches used for welding the blind areas

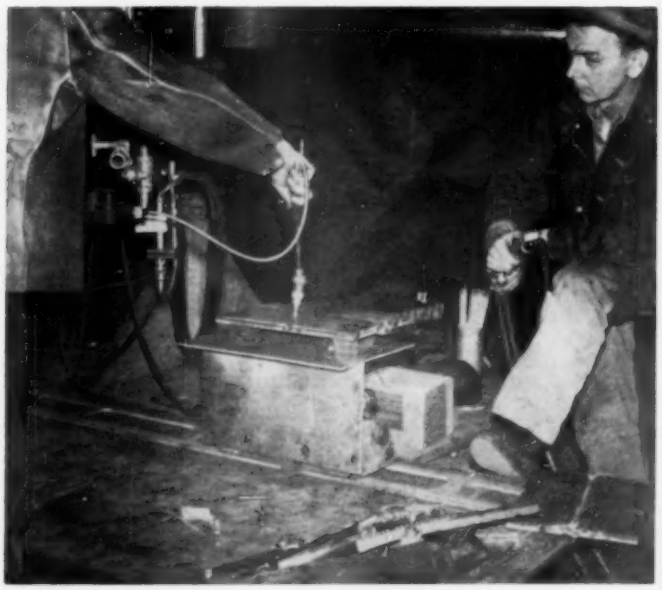

Fig. 9—Part of equipment used to establish welding procedures

In addition to the above equipment, two special torches were designed and made to weld the blade-cover subassembly to the disk, where all of the blind welding was encountered. Two torches were

necessary since one was required for welding the convex side of the blade, Fig. 6, and the other, Fig. 7, was used to weld the concave side. A cross section, typical of the construction of both torches, is shown in Fig. 8.

Welding Procedures

When the decision was made to design, make or modify equipment to be able to weld mechanically the blind or difficult areas of these parts, it was considered advantageous to do as much welding as possible in this manner. This would insure uniform weld-bead formation, sound welds (which probably could not be achieved with manual welding) and a duplication of quality from blade to blade.

Equipment used to establish welding procedures was the same power source, wire drive and controls which were to be used for production welding. A standard machine-welding torch with a special nozzle was used. The nozzle was reduced in diameter, extended in length and bent to simulate the requirements needed for production welding in the confined area between the blades. All of the welded samples were made in a fixture which was attached to a portable oxygen-cutting machine which was mounted on a track, so that the samples moved under the stationary mounted torch. The general arrangement of this equipment is shown in Fig. 9.

Initial samples representing actual joint cross sections were made from mild-steel plate to establish filler-wire size, wire-feed rate, weld-bead size and travel speed. After the optimum variables were established, SAE 4340 material was used to establish optimum variables for weld soundness and mechanical properties.

All welding was accomplished with a 600–700° F preheat and interpass temperature followed with an 800° F postheat and slow cooling. The first samples made were cross sectioned, polished, etched and examined for penetration and weld soundness. Satisfactory penetration was obtained after a considerable number of specimens had been examined, but there was porosity and some surface contamination in each sample. The first consideration as to the cause of the porosity was the possibility of the 5% oxygen-argon mixture being used for the shielding gas. Subsequent analysis made from weld-metal pads using 1 and 5% oxygen showed no appreciable change in or loss of elements to cause porosity. A summary of this phase of the investigation is shown in Table 1. The elimination of the porosity was accomplished by the addition of an auxiliary gas tube carrying straight argon for added shielding.

In welding samples for the selection of filler material with optimum physical properties, longitudinal cracks were observed in the welds using filler materials I, III and IV, Table 1, usually on the weld which was made last and, generally, in a weld which was slightly concave. All cracks were found after the welds had cooled to room temperature. Changing of variables did not show any consistent improvement in this problem, so the next approach was to check weld-metal chemistry. Based on the theory that hot-short cracking results from high sulfur and phosphorus, two of the available filler wires were selected, those with the lowest sulfur-phosphorus level. In each test weld, cracking could be duplicated with the wire with the higher-element content, and cracking did not occur using the lower-element content.

It was necessary to establish procedures using the modified machine-welding torch which was used to weld the blade-cover subassembly where the welding was readily accessible, as well as a separate schedule for the special torches used for the blind welding. For the first torch, joints were made using a joint which represented the actual part, which were cross sectioned and examined for soundness and penetration. With the same variables, beveled butt welds were made for transverse tensile, face and root-bend specimens. For the special torches, schedules were established on a full-sized simulated impeller, fabricated from mild-steel plate, from which samples were cut to examine for weld soundness. The simulated impeller, one of the torches and some of the equipment used are shown in Fig. 10.

The final procedures which were used are shown in Tables 2 and 3. It will be noted that amperage and voltage used were quite high for the droplet-type transfer. Actually, the transfer was probably some combination of the spray and droplet types, for the diameter wire used.

Table 2—Welding Variables Used to Weld Blade to Cover Subassembly with Modified Machine Torch

Wire diam, in.	0.045
Voltage	21–23
Current, amp	230
Contact tube to work—distance, in.	9/16
Travel speed, ipm	13
Shielding-gas flow, cfh	50

Table 3—Welding Variables Used to Weld Blade-cover Subassembly to Disk with Special Torches

Wire diam, in.	0.045
Voltage	22.5–23
Current, amp	230–240
Contact tube to work—distance, in.	1/2
Travel speed, ipm	13
Shielding-gas flow, cfh	50

Heat Treatment

In order to determine what over-all heat-treating procedure would result in the most satisfactory assembly properties, two groups of samples were run. The first was annealed-4340 stock which was welded with the established procedure, normalized, quenched and drawn to 269–302 Bhn (269–321 range desired). The second was normalized-4340 stock which was welded with the same procedure, quenched

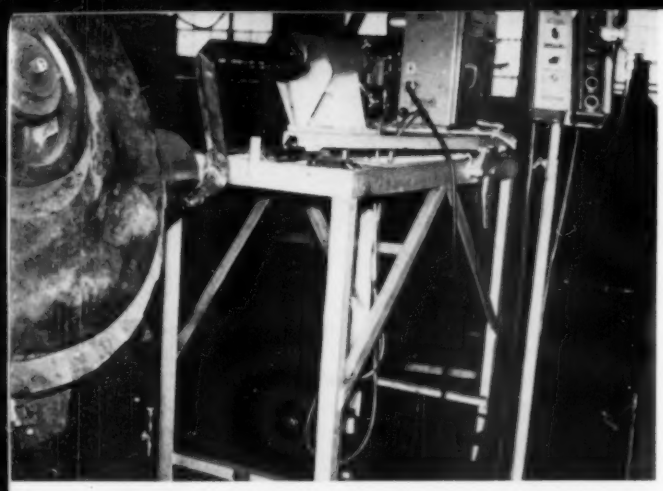

Fig. 10—A simulated impeller used for operator training, tooling and to establish welding variables

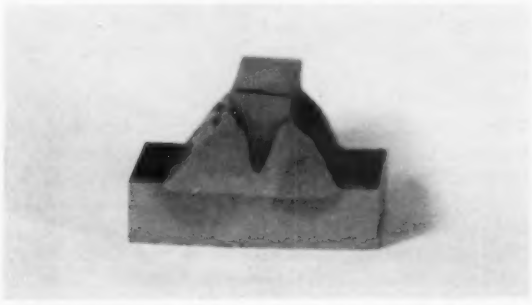

Fig. 11a—Macroetched cross section of weld, as welded

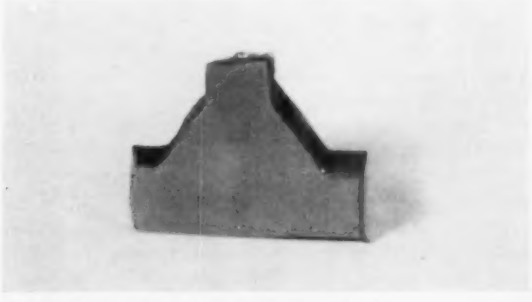

Fig. 11b—Macroetched cross section of weld, after quenching and drawing

Fig. 12—Interior of basic fixture showing electric elements embedded in the refractory lining

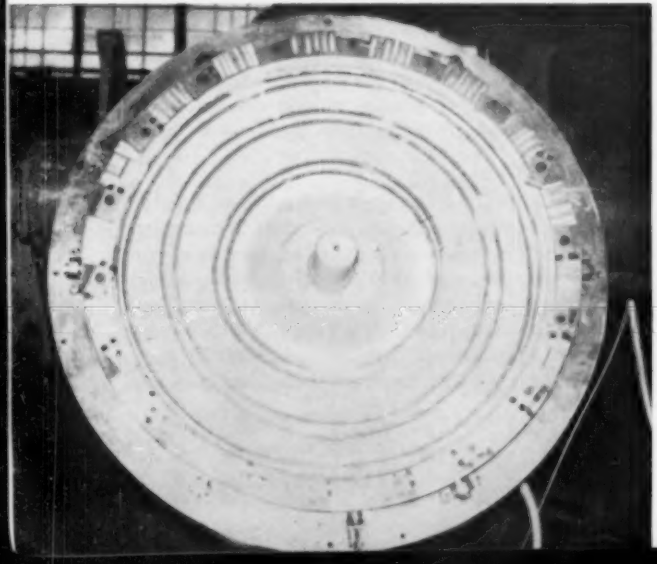

Table 4—Mechanical-test Results after Final Heat Treatment

	Ultimate tensile strength, psi	Yield strength by drop-in-beam, psi	Elongation, in 2 in., %
Annealed stock, welded, normalized, quenched and drawn	145,600	129,500	13.0
Normalized stock, welded, quenched and drawn	147,000	83,600	11.0

and drawn to 293–321 Bhn (269–321 range desired). Table 4 shows the mechanical-test results and Fig. 11 the macrostructures observed in the test pieces.

Since the first treatment resulted in a better yield strength and better ductility, and since it also showed a more uniform and finer structure, it was felt that a heat treatment to eliminate the effects of welding, prior to quenching and drawing, was important. These results indicated that an ordinary stress relief would be unsatisfactory.

After the final welding of the impeller, it was removed from the fixture and immediately placed into a furnace at 1600° F where it was held at temperature for $2^1/_2$ hr. It was then air cooled to room temperature. After cleaning, magnetic-particle inspection and repair of any defects, the impeller was then heated to 1525° F, held for $2^1/_2$ hr and oil quenched. It was then tempered at 1175° F for $2^1/_2$ hr.

Tooling

Due to the inherent air-hardening and crack-sensitive characteristics of the materials used on this

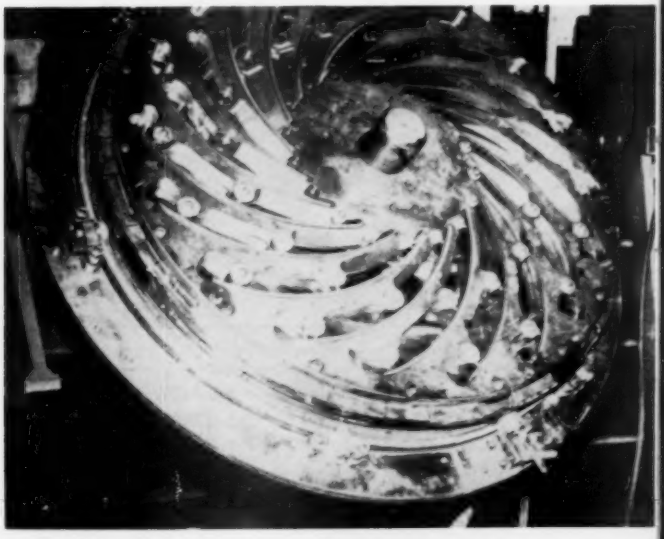

Fig. 13—Fixture used to locate and tack weld blades to cover

program, tooling was quite involved. The first consideration was to provide a fixture to be able to preheat and control interpass temperatures within precise limits. Secondly, the fixture had to be mounted on a rotating positioner with variable-speed control to accommodate the mechanical welding operation. The interior of the basic fixture is given in Fig. 12 which shows the electric heating elements used, embedded in a refractory lining.

It was deemed necessary that all blades be loaded into the fixture at one time so that preheating could be accomplished uniformly. At the same time, the fixture must be free to move during the preheat cycle, must hold each blade in the proper location, and the weld joint must be accessible for tack welding. The fixture used for the tack welding is shown in Fig. 13. It will be noted that this fixture has been made from a single plate with radial slots milled at each blade location. Three mechanically actuated cams hold each blade to the machined radius corresponding to the blade curvature and the entire mass is free to expand.

Expansion of the parts on heating was one of the major tool-design problems. However, shrinkage of the parts and fixtures on cooling to room temperature after welding also had to be considered. Concentricity of blade location with respect to the center of the cover had to be maintained accurately, yet the tools had been made so that they could be disassembled easily for subsequent parts. One of the ideas used in these tools may be seen in Fig. 14, which shows a serrated hub that holds the blades and cover concentric, holds the parts flat to the fixture and is easily removed after cooling. It consists of a threaded-plug assembly which expands the serrated hub to give a tight fit at room temperature. The serrations permit contraction of the cover hub upon cooling after welding. Similar parts were used to locate and hold the disk to the blade-cover subassembly.

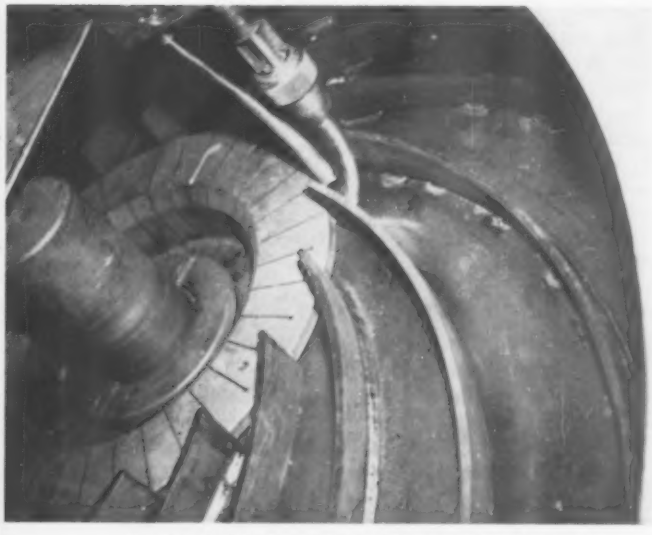

Fig. 14—Modified machine-welding torch positioned to begin a weld on blade-cover subassembly

Assembly and Welding

Before any production welding was permitted, a simulated impeller was completely fabricated. The cover, disk and blades were machined to impeller drawings from mild steel. Although the base metal was different from that used in production impellers, it provided the necessary operator training and pin pointed areas where trouble might be expected.

The cover was loaded into the positioner-preheat fixture with the blades and locating fixture mounted on top. The fixtures and parts were preheated to 600–700° F and the blades were then tack welded with a predetermined sequence. All tack welding was done with the inert-gas-shielded tungsten-arc process. This process was used in preference to the shielded metal-arc process because of less spatter and, also, because the bead shape could be controlled to eliminate grinding or removing the tacks before making the final machine welds. The completed tack-welding operation is shown in Fig. 15.

After the tack welding was complete, the parts were covered with asbestos blankets, postheated to 800° F, held for 1 hr at this temperature, and cooled slowly to room temperature. Although the foregoing was time consuming, any deviation from this procedure resulted in cracked welds and the mislocation of blades, which had to be replaced by repeating the above cycle.

After removing the blade-locating fixture, the parts were again preheated to 600–700° F. Welding was started on the convex side of the blade opposite the tack-welded side. Each weld was started at the widest part of the blade near the center of the cover with the weld progressing toward the blade tip. After each blade was welded, the positioner was rotated to the next position and welding was again started at the same location. After the convex side of all blades was welded, the machine torch was repositioned so that welding could be completed on the concave side of the blades in the same manner. At the wide end of each blade, there was about $1^1/_2$ in. which could not be completed with the machine-welding torch. This area of the blade and a similar area at each blade tip was finished with manual inert-gas-shielded tungsten-arc welding. The parts were then covered, postheated and slow cooled to room temperature. Immediately after removing from the welding fixture, the parts were placed in a furnace and stress relieved at 1200° F for $1^1/_2$ hr, and cooled to room temperature in the furnace.

After the parts had cooled, they were sand blasted and magnetic-particle inspected. If objectionable defects were found, they were first removed with a rotary burr, repaired by the tungsten-arc process, again using the 600–700° F preheat. Next, the outer perimeter of the cover was inspected for distortion by setting the center hub on a surface plate and checking with a height gage. If distortion ex-

ceeded more than 0.010 in. in the plane of the cover perimeter, it was necessary to straighten. This was accomplished by using a 750-ton press and a series of steel blocks. It was found that the parts could be straightened at room temperature without cracking any of the welds, even though the parts were deflected 0.025 to 0.035 in. to allow for springback.

After the above operations, the subassembly was machined so that the upstanding blade edge fit the disk contour, when it was fitted to the subassembly in its relative position. Next, each blade was machine beveled to the prescribed joint design. The subassembly at this point is shown in Fig. 16.

During the development welding with the special torches used for the blind welding, some spatter was encountered. This was believed to be caused by the acute angle of the torch nozzle to the weld joint and could not be entirely eliminated. However, even small particles of spatter which adhered tightly to the disk or blade could not be tolerated, as these surfaces were used for the tracking of both special torches. To eliminate this problem, the inside surfaces of the disk and cover between blades, and also the blades themselves, were painted with a heat resistant aluminum paint, except in the immediate weld area. It was found that this prevented the spatter from adhering to the metal surfaces and, if the paint did get into the molten weld, did not affect weld soundness.

The sequence of welding the disk to blade-cover subassembly was essentially the same as the previous operation. However, the basic and difficult difference was that the welding could not be observed visually and adjustments could not be made once welding had begun. From the previous description of the special torches, it will be noted that the torches are rectangular in cross section and are provided with a shoe which serves as a guide for the torch on the disk and against the blade. Just before a weld was to be made, the contact guide-tube height and angle of gas nozzle would be adjusted to a gage and secured with set screws to prevent movement. Another necessary adjustment to the equipment, prior to welding, was the position of the torch-holding gantry in relation to the positioner, fixture and workpiece. Here the positioner was tilted so that the workpiece would rotate at a 45 deg. angle, and the torch was positioned so that the flat guide shoe was in the same plane as the inside of the disk. This adjustment permitted downhand welding for better bead formation and the exactness of this adjustment controlled the proper tracking of the torches and the starting point of each weld. Figure 10 shows this part of the equipment in position for welding the concave side of the blades. For welding the convex side of the blades, the convex welding torch is mounted in the gantry and both are positioned on the opposite side of the positioner.

After the above adjustments were made and the parts were preheated, the welding torch was moved forward so that the torch nozzle was near the inner end or wide portion of the blade, where each weld was started. Actual welding was initiated by the operator pushing two buttons simultaneously. One button started rotation of the positioner, the other started welding power supply and wire-feed controls. Each weld was completed with the welding torch stationary and the workpiece being rotated by the positioner. One of the blades being welded on the convex side is shown in Fig. 17 where the blade tip is just about to pass under the torch nozzle to finish the weld.

After all blades had been welded on both sides, and while the parts were still hot, the ends of the blades were finish welded manually where the machine torches could not reach.

On the first operation of welding the blades to cover, the parts were stress relieved and straightened before the intermediate machining operation. It was found that this was not necessary on the final welding operation. There was apparently enough stiffness from the first subassembly after it was tack welded to the disk to prevent further distortion. This permitted the final weldment to be removed from the welding fixture at the postheat temperature of 800° F and immediately transferred to a furnace at 1600° F, where it was soaked for $2^1/_2$ hr, removed from the furnace and air cooled to room temperature. After examination for defects and the repair of such defects that were found, the complete wheel was given a final heat treatment, as previously described.

Final Weld Inspection and Repair

Inspection of the blind weld areas was just as critical as the open welding, but far more difficult. Both magnetic-particle and dye-penetrant inspections were used, after the parts had been sandblasted. It was necessary to use special probe lights, which could be bent around the blade curvature, to search for defects with magnifying dental mirrors. Fortunately, when defects were found, they were either at the beginning of the weld or at the blade end. The nature of most defects was porosity due to lack of gas shielding or minute cracks where the weld was probably exposed to cold drafts.

Where repairs were made, defects were removed with a rotary burr, preheated to 600–700° F and repair welded with a modified gas tungsten-arc welding torch, and immediately tempered at 1000° F for 1 hr.

Final Machining and Balancing

Throughout this program, every possible precaution was taken to prevent or control distortion because of the final balance requirements for a finished impeller. It was necessary to finish machine the inside surface of both the disk and cover prior to welding, as it was not feasible to do so afterwards. Although extra material was allowed on the outside of the above parts, there were still some irregularities to contend with from distortion and subsequent straightening. This was overcome by establishing

Fig. 15—General view of tack welding

Fig. 17—One of two special torches as a weld is being finished

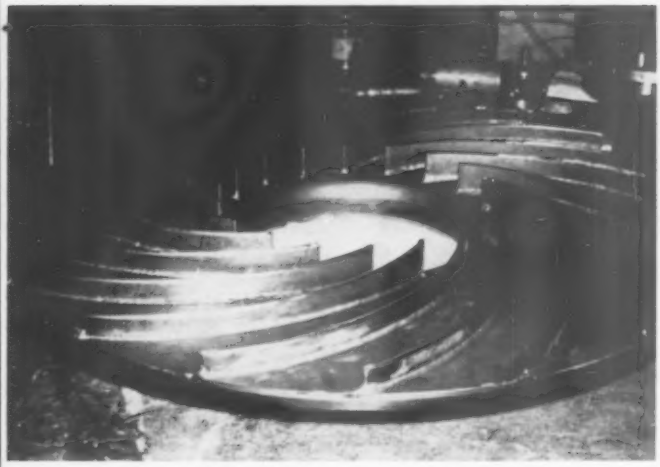

Fig. 16—A finished blade-cover subassembly

Fig. 18—One of the machine operations showing added material being removed

stock lines from the inside machined surfaces and making alternate cuts on the outside surfaces. Figure 18 shows the outer edges of an impeller which have been reduced in thickness from $^{3}/_{4}$ to $^{3}/_{8}$ in. by alternating cuts. Figure 19 shows a completely machined part where the outer edges have been reduced to $^{5}/_{32}$ and $^{3}/_{16}$ in.

After final machining, each impeller was dynamically balanced and oversped to 15% above the design operating speed. This particular impeller was designed to operate at 6000 rpm with a top speed of 925 fps.

Conclusions

It is invariably difficult to weld an assembly which was originally designed for riveting, and this part was no exception. However, the functional design of an impeller wheel used for centrifugal compressors does not permit too many changes which will improve welding conditions. We feel that, with the completion of this program, sufficient operator training, tool and equipment-design experience has been obtained to permit the welding of more complex designs in the future.

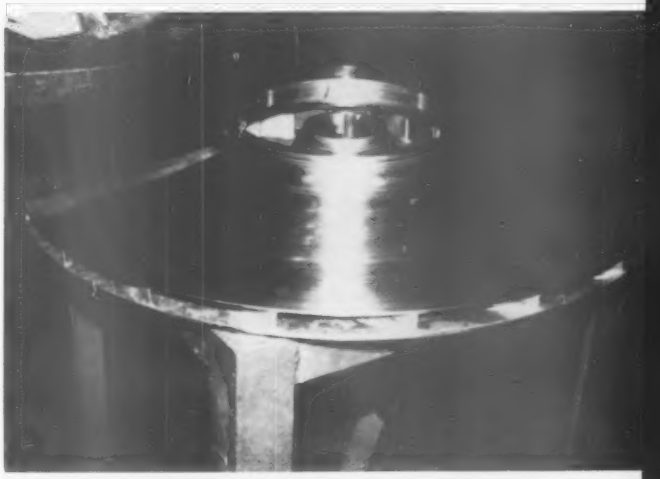

Fig. 19—Completed impeller after overspeed and dynamic balancing

References

1. Sopher, R. P., Jacobs, A. J., and Rippel, P. J., "Investigation of Weld-Metal Cracking in High-Strength Steel," THE WELDING JOURNAL, 34 (11), Research Suppl. 544-s to 552-s (1955).

2. Bicksel, H. J., Steinert, E. J., and Gamberg, E. R., "New Power Source Broadens Use for CO_2 Welding," *Iron Age* 182, No. 17, pp 61–63 (Oct. 23,1958).

Repair welding of grooved-out area containing crack in steam piping

Weldment

Failures Caused by Fabrication and Service

can be controlled by setting up and enforcing suitable procedures and by frequently checking the materials and products involved

BY HELMUT THIELSCH

Failures in weldments usually fall into the following five classifications:

Design
Material selection, specification and handling
Manufacture and shaping of materials
Fabrication and welding
Excessively severe service conditions

In some instances, the causes may fall into two or more of these. For example, a pipe steel containing manufacturing defects such as laminations may crack severely in the weld when the welding is done with electrodes depositing crack-sensitive weld metal. Notches in the root of weld deposits, acting as areas of high stress concentration, may fail in service environments involving stress corrosion.

Of the many types of failures found, only a few of the more common causes will be discussed. The samples, predominantly representing piping materials, actually apply to all types of weldments as pressure vessels, tanks, structures, welded equipment, etc. Service failures primarily related to structural and weld joint design and to the selection of the proper engineering materials were discussed in a previous article.[1] In this article fabricating and welding problems are of primary concern.

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Manufacture and Shaping of Materials

Commercial materials are *not* "perfect" products. Many nonhomogeneities are present originating in the melt and are carried through the various refining and forming stages into the final plate or pipe product. The majority of the nonhomogeneities are of little consequence, but some may and do affect adversely the service behavior and life of the completed fabrication.

The defects may be introduced by the steel maker or nonferrous metal producer into the ingot stage or

Fig. 1—Severe lamination in pipe frequently causing weld-metal cracking

during the subsequent rolling, forming or reduction of the ingot or billet.

Where the steelmaker's product is further formed or shaped by an intermediary, such as a forge shop or a fitting manufacturer producing elbows, tees or flanges, defective conditions can also be introduced.

Some of these defects are not readily detected, if at all, and in critical service applications may be responsible for failure of the fabrication.

Laminations

Laminations, scabs, tears, etc., probably represent the most commonly known discontinuity in steel materials. In most cases these laminations are not critical and are not likely to have any effect upon the service characteristics of the steel, since they are usually parallel to the steel surface.

Very severe laminations are shown in Fig. 1. This degree, of course, should be cause for rejection of the steel.

Whereas in welded-plate pipe the laminations tend to be parallel to the surface, in seamless pipe they may be inclined toward the surface of the pipe. The surface scab shown in Fig. 2 illustrates a heavier-than-usual lamination which, however, is not normally considered detrimental unless its depth exceeds 5% of the pipe wall thickness.

Laminations diagonal to the pipe surface should be considered more critical than those parallel to the pipe surface. In fact, plate with laminations parallel to the surface can be compared with the layered vessel construction employed by a pressure-vessel manufacturer. Nevertheless, heavy laminations, regardless of directionality, may lead to weld-metal cracking originating at the location where the weld deposit is fused into the lamination.

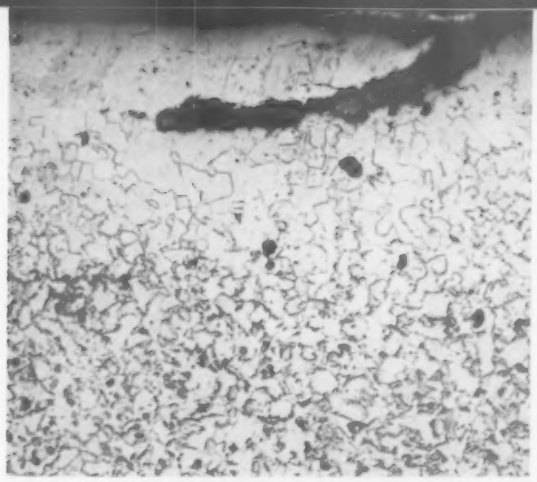


Fig. 2—Example of surface scab commonly found on many commercial pipe products which is not usually considered detrimental. × 100

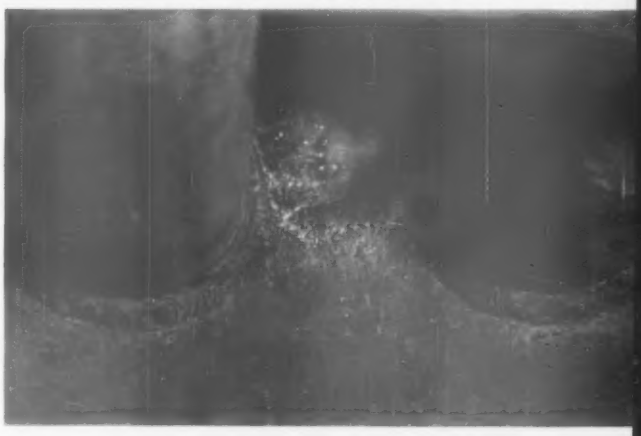


Fig. 3—Leak detected in soap-bubble test caused by surface scab reaching nozzle outlet hole drilled through shell of header

A significant percentage of the steel plate and pipe now in service contains substantial laminations. The large majority of these conditions is not likely to be detected unless nozzle or other openings are cut into the plate or pipe material. Where angular laminations reach the surface, they can cause liquid or gas seepage through the lamination from the nozzle to the surface. Where this condition exists, it is frequently detected in a Freon or soap bubble test (see Fig. 3). In a few instances, these tests and subsequent hydrostatic test have not revealed the presence of such angular laminations. After several years of service, however, the structures failed.

With service requirements becoming increasingly severe, the use of sound steel is of utmost importance. To determine the soundness of steel materials, very considerable effort is being devoted to the development of inspection techniques. To date, ultrasonic inspection has shown the greatest promise. Unfortunately, in its present state of development ultrasonic inspection does not always indicate the relative degree of "seriousness" of laminations or

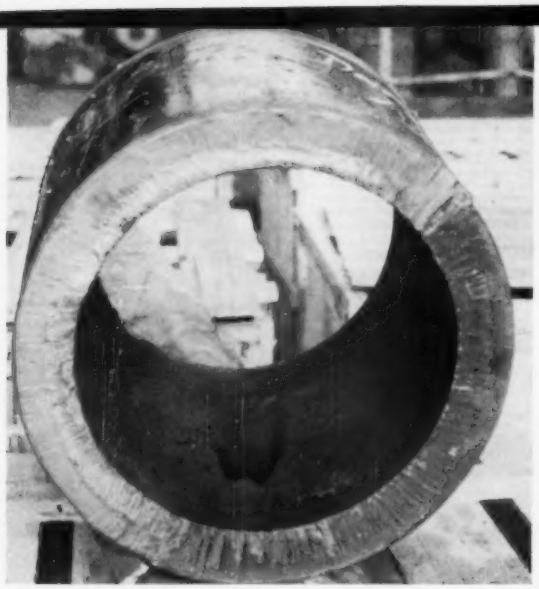


Fig. 4—$1^1/_4$-in. deep cavity at inside of 16 in. OD by $1^1/_2$ in. wall steel pipe certified by producer to be sound by ultrasonic examination

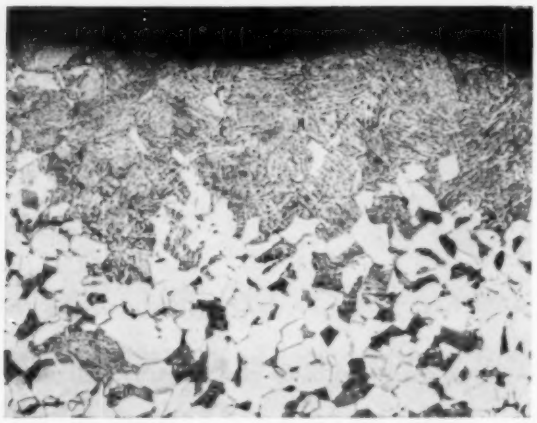


Fig. 5—Surface carburization revealed by metallographic examination of microstructure in $1^1/_4$% Cr – $^1/_2$% Mo low-alloy steel fitting. × 100

other structural discontinuities. For these reasons steel producers do not accept the return of plate or pipe materials "rejected" on the basis of ultrasonic inspection. Acceptance or rejection is therefore frequently decided on the basis of sectioning, trepanning or boat-shaped steel probing methods, which obviously are costly and undesirable since rewelding of the cavities may introduce more serious defects than were present originally.

The standard specifications are also of very little help in establishing acceptability standards. Where ultrasonic inspection is mentioned, all that is stated is "until suitable (ultrasonic inspection) standards are established, the basis for rejection of the material shall be a matter of agreement between the manufacturer and the purchaser." This certainly gives no comfort to the fabricator and the user of weldments who are concerned with the service performance of the finished product.

Fig. 6—Low ductility along weld seam causing cracking in bend test of coupon removed after stress-relief heat treatment from carburized fitting

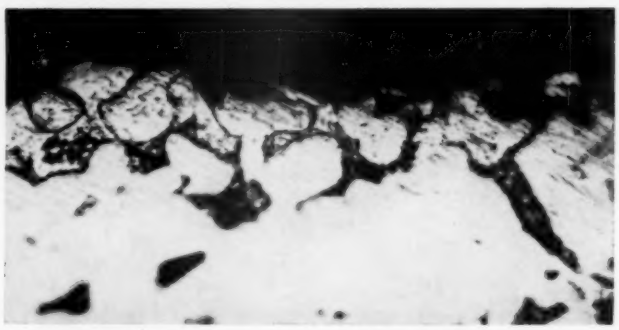


Fig. 7—Copper penetration into surface of $2^1/_2$% Cr – $^1/_2$% Mo pipe caused by contact of pipe with copper bearing material. × 500

Even where laminations or other discontinuities are evaluated by macroscopic examination, the Codes give no assistance in interpreting acceptability other than stating "each steel material that develops injurious defects during shop working or application will be rejected, and the manufacturer shall be notified." ASTM standard E45-51 which established a method for determining the inclusion content of steel carefully states that "this practice deals only with recommended test methods and nothing in it should be construed as defining or establishing limits of acceptability for any grade of steel." This lack of a proper standard has occasionally permitted steel pipe to be furnished with an ultrasonic inspection certificate which "attests" sound material containing serious defects. Figure 4 illustrates a pipe section thus certified which on the inside had a "lump" of metal apparently torn away during the extrusion process or subsequent shot blasting to reduce the wall thickness by 80%. The ultrasonic test report "proved" the steel pipe to be sound.

Surface Carburization or Decarburization

Surface metallurgy is very rarely considered in evaluating plate, pipe or similar materials. Nevertheless, carburization or decarburization may affect critically the welding and service characteristics of many ferrous materials.

During the hot forming into plate, pipe, fittings (elbows or tees), etc., care should be exercised to insure that excessive carburization or decarburization of the steel surface does not occur.

For example, in the forming of steel elbows involving conventional techniques, tubular sections are heated by means of gas burners to temperatures

Fig. 8—Failure in tube caused by notch formed along tube inside by tube drawing die

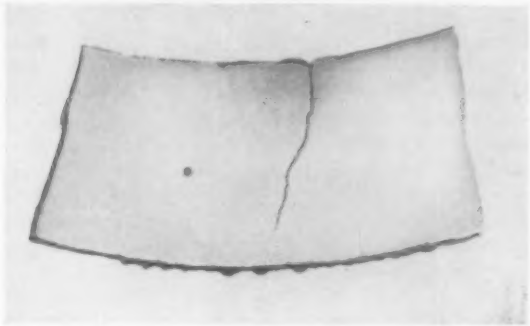


Fig. 9—Notch formed by seam weld along inside of same steel piping materials. Note smooth outside surface which made pipe appear as "seamless". × 7½

of the order of 1650 to 1850° F. The sections are subsequently "pushed" over special mandrels to form the elbows. Where the gas used to heat the tubular sections is not "neutral," but instead has a composition tending to be carburizing, the steel surface may become severely carburized. This may occur also in the gas heating of flat steel shapes for hot forming into half elbows and tee sections subsequently welded together and marketed as welded elbows and tees. Gas heating for pipe bending and straightening, and many other hot forming and shaping operations may produce similar results.

Figure 5 illustrates surface carburization in a welded elbow of a 1¼% Cr – ½% Mo low-alloy steel composition widely used in critical high-pressure high-temperature piping systems. Butt welds subsequently made on this material, by proper preheating to 500° F and stress relieving for 1 hr at 1325° F, failed in the bend test on bending by as little as 45 degrees, as illustrated in Fig. 6. Had a lug or guide plate for hanger attachment been welded to this fitting or a nozzle connection been made, failure might have resulted during service as result of severe stresses caused by pipe movement. Should a failure occur during service, it would have been likely that the fabricator who made the attachment weld would have been held responsible, instead of the fitting manufacturer. Even where a chemical analysis certificate had been furnished, the surface carburization would not have been discovered. Only weldability tests and, possibly, photomicrographs, would have revealed this condition. To require such tests on all materials furnished would have been prohibitive in cost.

Excessive decarburization can also be undesirable since the affected steel surface becomes more notch sensitive and susceptible to pitting by oxidation, stress corrosion, etc.

Non Ferrous Metallic Contamination

Where plates and pipe materials heated to hot-working or hot-forming temperatures come in contact with nonferrous metals, such as copper, lead, zinc, the surface of the steel will become embrittled due to penetration of these metals into the steel surface.

Figure 7 is a photomicrograph illustrating copper penetration into a 2¼% Cr – ½% Mo pipe material. Hot bending or welding of the affected areas would readily result in cracking.

It cannot be emphasized enough that it is extremely important for plate, pipe, fitting and similar materials to be very carefully handled during their processing from the ingot to the final shape ready for fabrication.

Mechanical Notches

Mechanical notches produced by pipe or tube drawing or extruding, by seam welding of piping or fittings, by machining or other operations used in producing the plate, pipe or fitting can also have a detrimental effect upon the service life of the fabricated material.

Figure 8 illustrates failure in a tube originating at a draw-die groove formed on the inside of the tube

Fig. 10—Failure along weld of two 3000-lb couplings identified as Type 304 stainless steel which was actually Monel. (Manufacturer's identification symbol has been blocked out).

Fig. 12—Welding end steel cap identified as Type 304 stainless steel which was found to be Type 430 stainless steel

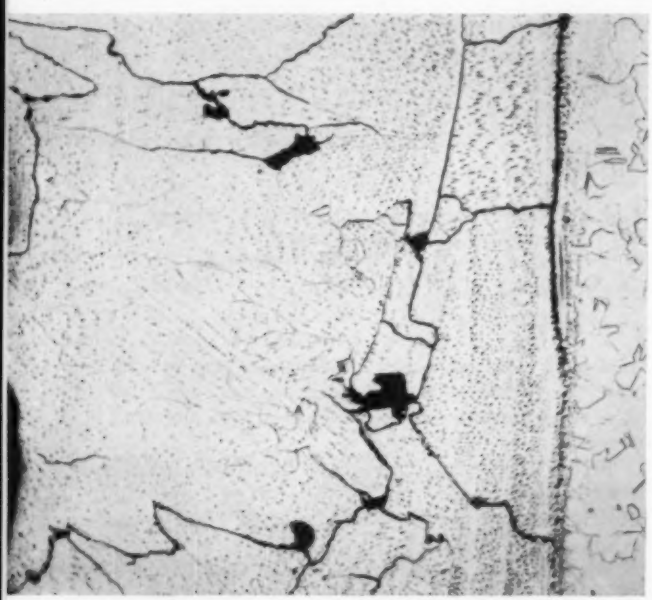


Fig. 11—Photomicrograph of bond between Type 308 weld deposit and Monel (70% Ni – 30% Cu) base metal illustrating "hot-short" cracking caused by copper penetration × 100

by the tube-drawing operation.

Figure 9 illustrates the notch which may be present in seam welds in carbon-steel piping (ASTM Specification A53) with a smooth outside pipe surface. There have been a number of instances where failures have occurred in seam-welded piping, frequently originating at notches present at the root of the weld.

Material Identification

Incorrect identification of alloys has been a far more frequent cause of failures than might be expected. The danger of mix-up is particularly great when applicable identification markings have not been applied directly to the surface of the alloy by die stamping. However, even on die-stamped products, a significant number of errors has occurred.

Figure 10 illustrates two 3000 lb couplings which had failed after being welded to a Type 304 stainless steel header for a nuclear installation. The material had been purchased as Type 304 stainless steel. To avoid possible mix-up in the fabricator's shop the couplings had the Type 304 markings applied directly to the surface by the manufacturer. Certified mill test reports also attested that the chemical composition conformed to ASTM Specification requirements. The so-marked Type 304 couplings were welded to the Type 304 header and failed in a service test. Subsequent examination revealed that the couplings actually were Monel. Welding of Monel with stainless-steel electrodes results in brittle joints (Fig. 11) due to the copper content in Monel. It is fortunate that the pressure test revealed the defective joint. It might have held sufficiently during the brief test and then failed subsequently during service. In a radioactive piping system, such a failure might have made the plant inoperative for a long time.

Another example of material mix-up is illustrated in Fig. 12. The Type 304 stainless-steel welding-end cap shown actually was Type 430.

A number of service failures have occurred in steam power plants where carbon steel sections identified as chromium-molybdenum alloy steel

Fig. 13—Poor pipe-joint fit-up providing notch resulting in stress-corrosion cracking

Fig. 14—Poor pressure-vessel-joint fit-up providing notch resulting in stress-corrosion cracking

have been welded into critical high-temperature high-pressure pipe lines requiring alloy steels.

Where failures are due to improperly identified materials, the welding fabricator is generally blamed for the mix-up and is frequently held responsible for resulting losses. It is therefore highly advisable that the manufacturer apply permanently affixed identification markings to the surface, preferably by die stamping.* Otherwise, when welds fail due to the use of the incorrect base metal, the fabricator generally will experience extreme difficulty in proving the origin of the incorrect alloy. Most suppliers of metals and alloys are extremely reticent to admit to defects in their materials.†

Some manufacturers, because of ignorance, competition or other reasons, also upgrade materials into a higher quality grade. For example, at least one domestic fitting producer has on occasion made carbon-steel elbows out of A53 pipe, even though the applicable ASTM Specification on seamless welding fittings, A234, lists as permissible raw material only A106 pipe material. A106 pipe is a higher quality pipe material than A53 pipe, which is not considered suitable for the service involving higher temperatures and/or pressures. Where failures cannot be traced to the wrong raw material in the elbows, because of the absence of identification markings, the welding fabricator would have difficulty establishing that he was not responsible for welding an improper material.

*The Pipe Fabrication Institute in Standard ES11-1959 has issued a "Recommended Practice for Permanently Affixing Identification Symbols to Fabricated Piping" covering the major ferrous and nonferrous pipe materials.

†One steel mill recently wrote its customers:

"This is to advise you that ABC Co. has, for a long time, refused to sell its pipe mill rejects and that a few which are encountered in our inspection are immediately scrapped and thrown back into the furnaces for re-melt.

"The purpose of this letter is to advise that our policy remains the same, and that any rejects which you encounter within our size range and with which you may have had trouble, obviously must be of some other manufacturer."

Fabrication and Welding

Statistically, only about 20% of service failures in weldments can be ascribed to improper welding techniques. Nevertheless, they do occur, particularly where a fabricator does not have sufficient experience and know-how in the welding of some of the more highly alloyed steel and nonferrous materials. A substantial number of service failures may also result from irresponsible cost cutting. Unfortunately, the continuously sharpening competitive pattern over the past years has placed excessive emphasis on cost cutting, and this may result in sloppy workmanship, improperly prepared welding specifications, insufficiently trained and improperly qualified welders, and the complete absence of inspection. Although the outside appearance of both good and defective welds may be similar, the welds with hidden defects may fail in service. Since service failures generally tend to result in loss of production, the actual final cost may be very much higher than if the user of the weldment had purchased a somewhat better class of welding.

Joint Fit-up

Good joint fit-up is considered essential in the fabrication of piping for critical main steam power-plant service. To accomplish the best possible fit-up, the inside diameter of pipe is generally machined to provide good matching of the pipe ends to be welded together.

In piping for less critical systems and in vessels for many service applications, fit-up is generally not considered as critical. However, in some service environments the notches formed by poor fit-up can serve as local stress raisers for the initiation and propagation of cracks.

Figures 13 and 14 illustrate service failures by cracking in a badly fitted pipe joint (welded from one side only) and a vessel joint (welded from both sides). The notches formed by the poor fit-up permitted the initiation of stress-corrosion cracking.

Weld-metal Cracking

Weld-metal cracking is closely related to the welding process and welding techniques employed and the materials selected. It is, therefore, essential that the welding procedures followed and materials used be thoroughly evaluated, including tests under such unfavorable conditions as may be encountered in shop and field welding.

The fact that a weld joint has been inspected with various inspection techniques is no full guarantee of soundness. Small cracks, inherent brittleness or other defects may have been introduced.

For example, where the inert-gas tungsten-arc root-pass welding process is used, the difficulty in determining root-pass cracks, even by X-ray radiography, is illustrated in Fig. 15. The root in the 6 in. $1^1/_4\%$ Cr – $^1/_2\%$ Mo Schedule 80 (0.432 in. wall) pipe, which was made by inert-gas tungsten-arc root-pass welding, contained the $2^1/_2$-in. long crack shown in Fig. 15A. As is standard practice,

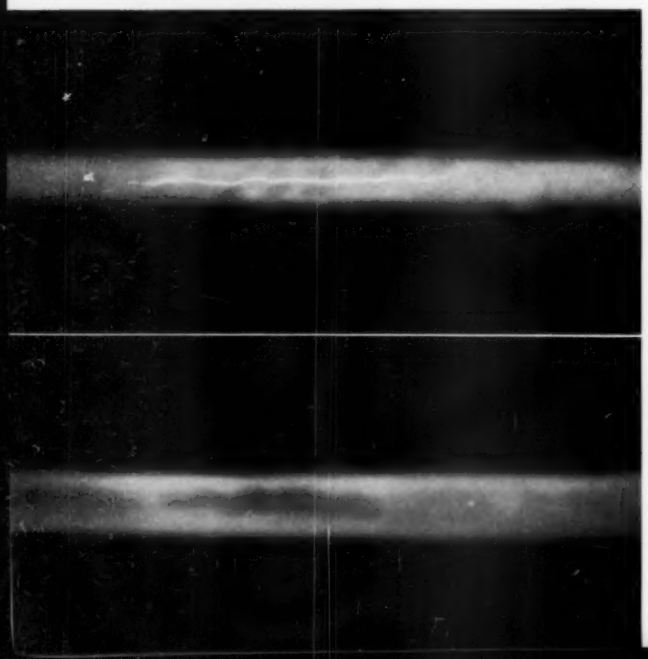
the subsequent passes were made by shielded metal-arc welding with 1¼ Cr – ½% Mo (AWS-ASTM E8016-B2) covered "stick" electrodes. After the first cover pass with the covered electrode, the root-pass crack was no longer visible by X-ray radiography (see Fig. 15B). Subsequent sectioning of the completed weld, involving nearly ten shielded metal-arc welding passes, revealed, nevertheless, that the root-pass crack was still present (see Fig. 16).

The "disappearance" of the crack was caused by the shrinkage of the first covered-electrode pass made on the inert-gas tungsten-arc root-pass which drew together tightly the crack in the root pass. Certainly, the potential danger of such cracks has not been lessened by their being closed up mechanically. Radiographic techniques employing gamma rays, or some of the radioactive isotopes, are less sensitive than X-rays and would be even more unlikely to reveal the presence of the root cracks.

Detection of these cracks in chromium-molybdenum alloy pipe steels is further complicated by the continuous preheat requirements of most specifications, which state that the preheat temperature (usually between 400 and 600° F) must be maintained without interruption until the whole weld has been completed or until at least several layers of weld metal have been deposited.

For example, Pipe Fabrication Institute Standard ES(M)8-1958 states that "welding on 1% Cr – ½% Mo to 3% Cr – 1% Mo materials may be interrupted at any time, provided that a minimum of at least ⅜ in. thickness of weld deposit or 25 percent of the welding groove is filled, whichever is greater." On 5% Cr – ½% Mo welding should not be interrupted unless a partial or complete stress-relieving heat treatment is given.

Fig. 15—Crack in root pass of pipe butt weld made by inert-gas tungsten-arc welding. (A–top) Radiograph of root pass illustrating extent of crack. (B–bottom) Crack no longer visible after deposit of subsequent weld pass made by shielded metal-arc welding



The American Welding Society Committee on Piping and Tubing states in its "Recommended Practices for Interruption of Heat Treatment for Low Chromium-Molybdenum Steel Piping Materials (D10.3-55T) that, on all of these steels, preheat should in no case be interrupted before 1/3 of the wall thickness or two layers of weld (whichever is greater) are deposited.

Inspection of the root weld pass by radiographic technique would require special hot-radiograph fixtures.[2]

Welding Procedure

Not enough can be said about the necessity to evaluate welding procedures carefully, particularly where new welding processes are involved.

In the inert-gas tungsten-arc welding of light wall stainless-steel piping (Schedules 5 or 10), a rough heavy oxide scale is frequently produced on the underside of the joint, as illustrated in Fig. 17. To avoid this scale formation, the best procedure is to introduce a so-called purging gas as argon, helium or nitrogen on the underside of the joint. Where large-diameter piping is involved, another procedure used is to grind away the heavy scale and then "back-weld" from the inside. Although the resulting weld quality may not be as good as that

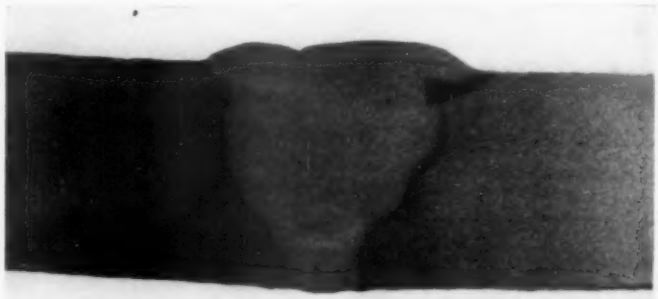
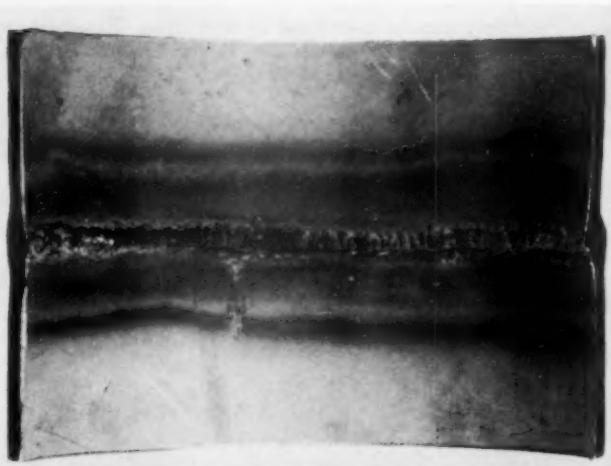


Fig. 16—Cross section of weld illustrating crack in root pass not visible by radiographic examination of second or subsequent weld passes

Fig. 17—Rough "cauliflower" type of oxide scale formed on the underside of welds made by inert-gas tungsten-arc welding in stainless-steel materials. X ½



of a weld made by purging, it may be acceptable in the majority of applications. In the grinding and back-welding technique, it is frequently difficult to ascertain that all of the scale has been ground away and that the groove made by grinding is centered above the joint. Where the groove is made too narrow, there is a tendency to offset the groove from the weld center and leave an undesirable lack-of-penetration area. Since the grinding marks tend to smear over the lack of penetration area, this offset might not be readily noted.

Since grinding is costly, the grinding operation is sometimes eliminated by some welding shops. Back-welding is subsequently done by inert-gas tungsten-arc welding over the heavily scaled area. This, however, is poor practice since it tends to bury the scale and may result in cracking, as illustrated in Fig. 18. Since these cracks may not penetrate to the outer surface, they are generally not recognized. In fact, the over-all visual appearance of such welds may be as "clean" as a properly ground and back-welded or a purged weld. However, during subsequent corrosive service, these scale (oxide)-filled cracks may open up and result in ultimate leakage of the corrosive solution.

Occasionally, special proprietary back-up fluxes are painted on the underside of the joint to protect the metal from oxidation. Unfortunately, almost all of these fluxes become extremely adherent to the underside of the weld. Since even mechanical wire brushing is likely to be insufficient to remove the flux scale, grinding is usually necessary. In several actual instances, the flux scale was also "removed" by back-welding, which produced a "clean" appearing although defective weld.

Since visual inspection is frequently the only criterion of acceptance of light-wall stainless-steel piping, a purchaser viewing a smooth weld surface may be of the erroneous, comfortable belief that his pipe welds are sound and of quality comparable to the base metal.

Excessively Severe Service Conditions

When the service becomes more severe than the conditions for which the fabrication had been originally designed, failures may also result.

Most common are failures caused by unexpected corrosion, excessive service loads or pressures, thermal[3] or mechanical shock, overheating, corrosion-erosion, etc. An example of unexpected corrosion is illustrated in Fig. 19. After 6 months of service involving water at 140° F, the Type 304 ELC stainless-steel piping failed due to severe corrosion.

Fig. 18—Cross section of stainless-steel weld in which cauliflower scale has been "buried" by making weld pass over scale formed on underside of initial weld pass. X 12.

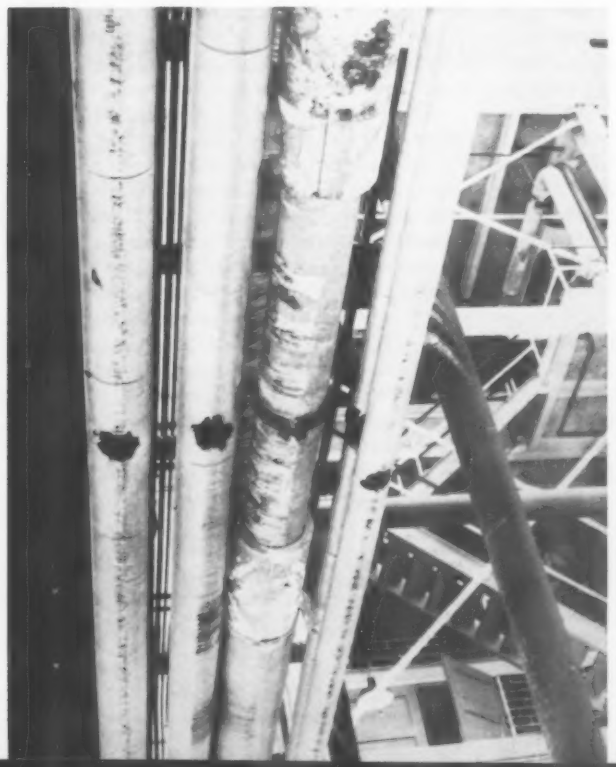


Fig. 19—Corrosion along seam welds of Type 304 stainless steel piping caused by chlorides dissolved in water

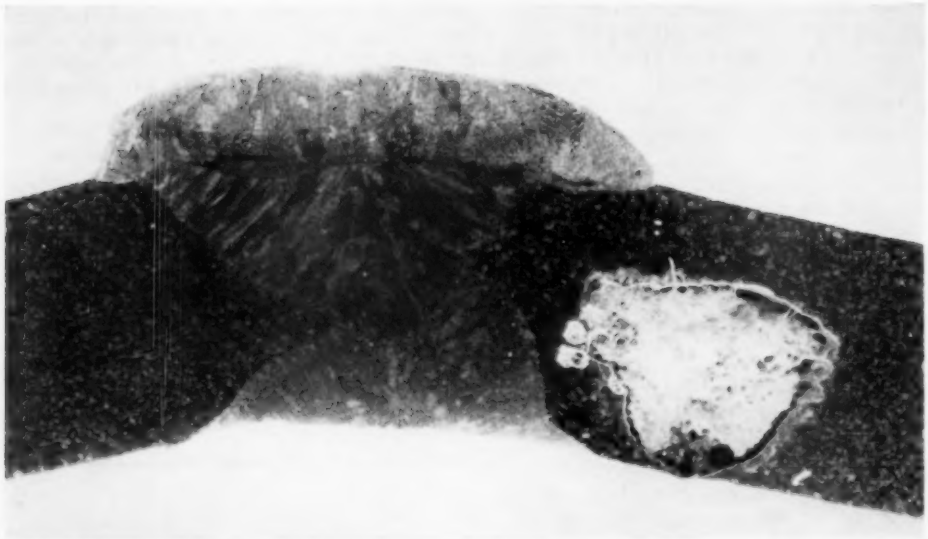


Fig. 20—Cross section of pitting attack caused by chloride corrosion. X 13

Fig. 21—Thermal shock failure in Type 316 socket weld joint

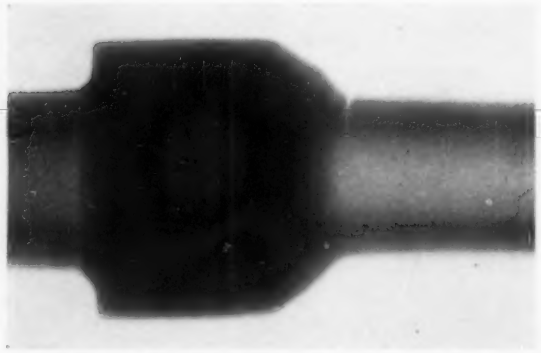


Fig. 22—Radiograph illustrating crack origin at "notch" formed between weld and stainless-steel tube

Subsequent examination revealed that corrosion was most severe along seam welds in the pipe (see Fig. 20). The attack was caused by an unusual and unexpected amount of chloride in the water conducted through the piping system. The final solution was to replace the seam-welded stainless-steel pipe with wood-lined steel pipe.

A thermal shock failure in Type 316 stainless steel is illustrated in Figs. 21 and 22. Had thermal shock been expected, the weld joint should have been designed to provide a more gradual change in surface contour, blending more smoothly into the pipe surface.

Conclusions

The examples of service failures shown actually represent only a few of the several hundred causes of failures collected from over 1000 service-failure investigations conducted during the past six years.

By far, the majority of the failures investigated were due to causes other than defective welding. Although the initial reaction to failures in weld deposits was to place blame on the weldment fabricator, thorough subsequent metallurgical examination frequently showed that there were other causes.

Nevertheless, many weld failures have been caused by defective welds. Usually they result from insufficient know-how or poor welding, supervision and inspection.

Since it is difficult, and often impossible, to detect the presence of defects in the finished products, it becomes highly advisable in critical systems to check periodically the soundness of materials and weldments.

References

1. Thielsch, H., "Service Failures in Pipe Weldment," WELDING JOURNAL, **39**(5), 488–495, (1960).
2. Thielsch, H., "Making Quality Pipe Welds Today," *Power Engineering*, **63**, 64–66 (December 1959).
3. Thielsch, H., *Thermal Fatigue and Thermal Shock*, Welding Research Council, Bull. No. 10, April 1952.

Practical Welder and Designer

Automatic metal removal, prior to welding operations, can be quick and efficient when using compressed-air carbon-arc cutting torch

Fig. 1—Operator is positioning the automatic gouging torch beside a tank mounted on rolls. The exterior welded seam is to be removed. On the inside of the cylinder can be seen the results of automatically deposited welds

Tank Fabrication Aided by Automatic Gouging Tool

The Sistersville Tank Works, Inc., of Sistersville, W. Va., has, for many decades, been fabricating heavy steel tanks and equipment for numerous industries throughout the Ohio Valley and the Charleston, W. Va., area. The company began operations about 65 years ago. Principal products at that time were oil well storage tanks and other special equipment for the then infant oil industry.

Today, the products manufactured are heat exchangers, heavy steel columns and pressure vessels under code specifications. Fabrication of the heavy steel plate used in these products naturally involves welding. In the majority of cases, a 100% weld penetration is required and the weld deposits are required to be of the highest quality for uniform strength of the structures. This poses two main problems in the shops. First, when heavy steel plate sections are joined by welding, the mating edges must be prepared to insure complete penetration of

Fig. 2—Removal of temporary exterior weld is begun. As the cylinder turns, a clean gouge is produced for deposit of permanent weld metal. Electrode feed controls on the gouging torch are synchronized with turning rate of rolls for depth of gouge desired

Based on a story by Arcair Co., Lancaster, Ohio.

the weld deposit; secondly, even top-notch welders occasionally make mistakes or the malfunction of automatic welding equipment can produce a section which must be removed and rewelded. To detect imperfect welds, all seams are inspected with X-ray equipment as required by code.

Former methods of beveling included pneumatic chipping tools, manual grinding, and oxygen cutting. These methods were too slow for their needs and had other disadvantages. To prepare circumferential seams for welding, the company has adopted a new technique. They use an automatic compressed-air carbon-arc gouging torch. Instead of prebeveling sections of metal for welding, the square edged parts are fitted together and tack welded on the exterior of the tank. The vessel is then welded on the inside with the submerged-arc welding process. With the tank mounted on rolls, the automatic gouging torch is then used to remove the temporary outside weld and form a U-groove. The depth of the U-groove is determined by the operator who establishes it with the electrode feed adjusting knob when sound metal is reached at the root of the interior weld. Operation of the cutting torch is simple. A consumable special-carbon graphite electrode is fed toward the seam at a predetermined rate of speed, which is in conjunction with the turning rate of the moving tank for the depth of gouge desired.

The arc-cutting torch has, as its only auxiliary requirements, power from most any good welding machine and a supply of ordinary compressed air. The cutting torch is operated from a 400-amp motor-generator type machine set at about 325, and 90 psi of compressed air are supplied from the shop air line. Both the air and the current are piped to the torch through a single concentric cable. Direct current, reverse polarity is used. When the electrode in the torch is brought close to the work, an electric arc is formed. Heat from the arc melts the metal and simultaneously jets of compressed air from the torch head blows the metal away. The melting and removal of molten metal continue all the time the tool is in use producing a clean and uniform groove in a mere fraction of the time required to do this work by other methods.

The automatic compressed-air carbon-arc torch is mounted on a pedestal beside the tanks. As the tank revolves past the torch, a bright, clean groove replaces the manually deposited weld metal in the seam. After a light grinding, the groove is then re-

Fig. 3—In a matter of a few minutes, the job is almost completed. The longitudinal seam prepared by a manually operated torch can be seen in this photo. The solidified metal on the edge of the groove is easily and quickly removed

Fig. 4—This view of the gouged seam shows the exceptionally clean condition of resulting work. A cursory grinding clean-up operation was made to clean the surface, although it was not required to remove slag. Because metal is not oxidized during removal operation, no grinding is needed in the gouged area itself

welded, with automatic equipment this time, to attain 100% penetration. The cost of electrode used to prepare the $55^1/_4$-in. diam seam on the cylinder shown in Figs. 1 through 4 was less than one dollar. Time involved: under 5 min.

For longitudinal seam preparation, a hand-model torch is used. The manual torch is used also for removing defects, cutting stainless steel, etc. The hand-operated model will gouge at speeds up to 30 ipm, as will the automatic version. Among the advantages for using the automatic torch are uniformity of depth and straightness of the cut or gouge, because the tool is held in a stationary position. The quality of the gouge produced may be seen in Fig. 4.

Stud Welding Aids in Upgrading of Old Bridge

BY V. M. ROMINE

V. M. ROMINE, deceased, was Engineer of Bridge and Traffic Structures, Illinois Division of Highway.

A 1500-ft. long Illinois bridge was recently converted to provide a greater load carrying capacity at very little additional cost to the state. This was effected through the use of composite construction during the replacement of a concrete slab roadway

wherein the load was increased from an AASHO (American Association of State Highway Officials) rating of H18-S15 to the equivalent of H20–S16.*

The prime reason for reconstructing the bridge was the deterioration of the 7-in. thick roadway, although undesirable vibration and live load deflection were also factors in deciding to rebuild. Steelwork was considered structurally adequate. By bonding the new concrete slab to the steel beams, vibration and deflection were considerably reduced.

Since the concrete had to be replaced, composite construction was considered the most economical method of stiffening the structure. If it had not been necessary to replace concrete, it probably would have been more economical to upgrade by welding cover plates to the bottom flanges of the beams. Cover plates would have increased steel stiffness but probably would not have reduced vibration as much as composite construction. Under the circumstances, no cover plates were used.

Shear-connector studs, each 4-in. long and $^{7}/_{8}$ in. in diam, were used in the composite design because of their speed of application. The selection of shear connectors eliminated the possibility of warpage in the structural members which is sometimes encountered when prolonged arc time is required in the fillet welding of structural shapes or other type connectors.

A total of 24,160 studs were end-welded to the upper flanges of the bridge girders (Fig. 1). The studs were welded four in a row with rows approximately 6 to 18 in. apart and were installed at a rate of about 3 studs per minute. In addition to the rapid speed of placement and the elimination of distortion, the use of end-welded studs simplified installation of the shear connectors near rivet heads on the plate girder spans. Furthermore, the use of end-welded studs facilitated the placing of reinforcing bars (Fig. 2).

Traffic was maintained on one-half of the bridge, while the other half was being rebuilt.

* The H18-S15 rating refers to load carrying capacity for traffic up to trucks of 18-ton capacity with 15-ton semitrailers. The H20-S16 means load carrying capacity for 20-ton trucks with 16-ton semitrailers.

Fig. 1—Studs being end-welded to upper flange of bridge girder

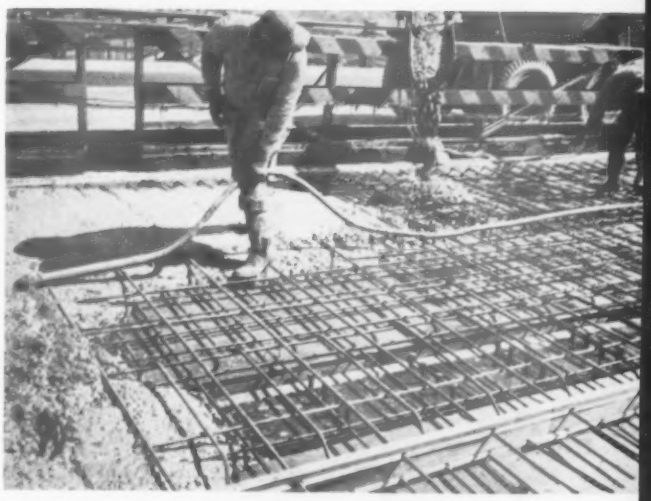


Fig. 2—Use of end-welded studs facilitates placing of reinforcing bars and permits easy movement of workmen during pouring of concrete

New Design in Modern Living

BY A. H. BUTLER, JR. AND J. L. THOMAS

Casual, carefree living is becoming a byword in every phase of modern life. This trend has exerted a strong influence on the metal-furniture market. Manufacturers of office, dinette and outdoor metal furniture see excellent prospects for long-term growth. The market is about doubling every ten years, and should reach $1.2 billion by 1970.

A. H. BUTLER, Jr. is a Welding Sales Engineer, Linde Co., Los Angeles, Calif., and J. L. THOMAS is a Welding Sales Engineer, Linde Co., Cleveland, Ohio.

Fig. 1—In less than 50 sec, two gas tungsten-arc welders tack weld the back, seat, arms and front legs of this aluminum office chair

Fig. 2 — Corners of aluminum-channel seat frame are gas tungsten-arc welded in subassembly operation. Filler rod requires no flux, due to shielding flow of argon

Fig. 3 — Aluminum seat frame is joined to office chair frame using gas tungsten-arc welding with filler-rod addition

Fig. 4—These bar swivel stools are produced with gas metal-arc spot welding

Fig. 5—Gas metal-arc spot welding at four-position welding fixture boosts output 125% on dinette-chair frame

In office furniture, largest segment of the industry, metal now accounts for 81% of office furniture sales. Styling plays an important part, even influencing purchasers to replace furniture which is serviceable.

One of the first manufacturers of aluminum office chairs is General Fireproofing Co., Youngstown, Ohio, who used oxyacetylene welding and flux-coated aluminum rod to fabricate the chairs. Production problems were experienced with oxyacetylene welding, but little could be done about them until a better welding process appeared.

One of the problems which occurred was weld porosity, resulting from moisture absorption and instability of the welding flux. Because the flux coating obscured pinholes in the weld, these could not be detected until the chairs were sent through the strong acid electrolyte in the anodizing tank—one of the last stations in the production line. Repairs sometimes consumed as much as *60 man-hours* in a two-shift interval.

Flux contaminated acid and water-wash tanks, as well as anodizing tanks. Also, weld craters occurred which appeared darker than the surrounding areas when anodized, requiring heavier and darker touch-up in color anodizing.

With complete conversion of the assembly line to inert-gas-shielded tungsten-arc welding, the company eliminated all problems due to welding flux—since the argon-shielded welds require no flux. Uncoated 5356 aluminum alloy rod is now used where filler metal is required (see Figs. 1 to 3). Tungsten-arc fusion welding of chair-leg seams and bottom leg blocks eliminates filler rod completely. Finally, any possibility of corrosion of chairs in use, due to flux inclusion in close-fitting parts, has also been eliminated.

With tungsten-arc welding, weld bead and penetration have been improved. Distortion due to warpage has been reduced, permitting exact dimensioning of chairs and the production of entirely new designs, such as the functional "stacking chair."

In the over-all production picture, the manufacturer attributes 50% cost savings and greatly improved product appearance to trouble-free tungsten-arc welding.

Tailored to Please

One of the strongest influences on dinette, summer and casual furniture has been the trend to suburban living. Small kitchen-dining areas, patios, outdoor barbecues and swimming pools have created new markets in recent years.

Inert-gas-shielded metal-arc spot welding is helping to bring strong, slender metal furniture into the modern home. At Nuchrome Seating Co., Los Angeles, Calif., metal-arc spot welding produces smooth and spatter-free welds at the highest production rates obtainable for manual assembly.

While a helper loads and unloads dinette chair frames from a four-position rotary fixture, the welder simply places the spot-welding gun in the proper location on the frame and pulls the trigger. In less than one second the spot weld is completed. Only six spot welds are required per chair. Since metal-arc spot welding does not disturb the paint adjacent to the weld area, chair frames are painted prior to welding.

Bar swivel stools withstand more abuse than dinette chairs, and thus require more spot welds: 4 welds on the foot ring support and 8 welds on the swivel section. A single loading fixture suffices for all of the spot welds required (see Fig. 4).

The manufacturer has completely replaced other welding methods by inert-gas-shielded metal-arc spot welding, and has tailored its production line to the process. Not only has production rate increased by 125%, but unit cost has dropped because no postweld cleaning or buffing is necessary (see Fig. 5.)

Society News

Pittsburgh Meeting Reflects Welding Trends

Developments in Welding and Other Activities Arouse Lively Interest in Fall Meeting Program

Pittsburgh, the hub of America's steel industry, became the center of AWS activities for four days as the National Fall Meeting convened at the Penn-Sheraton Hotel from Sept. 26th to 29th, 1960. Prominent among the solid accomplishments this fall was the coverage of several important aspects of welded structural members. Emphasis was definitely on lighter weight, greater strength and higher productivity.

Getting under way for the 1960 National Fall Meeting, the registration area was a busy focal point

J. E. Dato, genial major-domo of AWS National conventions, opened the 1960 Fall Meeting

AWS President R. D. Thomas, Jr., during his welcoming address, stressed the need for increased productive efficiency in American industry

Other events on the well-balanced program helped to round out a full schedule. The high quality of the technical papers presented, the many committee meetings, the numerous social activities—all contributed to making this meeting an outstanding success.

A hearty tribute is due the Pittsburgh Section and its Arrangements Committee for handling the numerous details connected with the Fall Meeting. Many weeks of careful preparation and much behind-the-scenes work was required to achieve the smooth operation. It was a fine job.

President Thomas Opens Meeting

Starting with the opening session on Monday, a full schedule of morning and afternoon events kept members and their guests completely occupied. President R. D. Thomas, Jr., made the opening address in which he pointed out the serious implications for this country in the growing competitive strength of Europe. He set forth the steps by which the welding industry can help to meet this foreign competition, stressing an increase in high-production techniques and the means favorable to this end.

Following President Thomas, three guests, representing cooperating societies, brought their greetings. They were E. K. Timby, a director of the American Society of Civil Engineers; B. G. Johnston, chairman of the Column Research Council of the Engineering Foundation; and D. T. O'Connor, president of the Society for Nondestructive Testing.

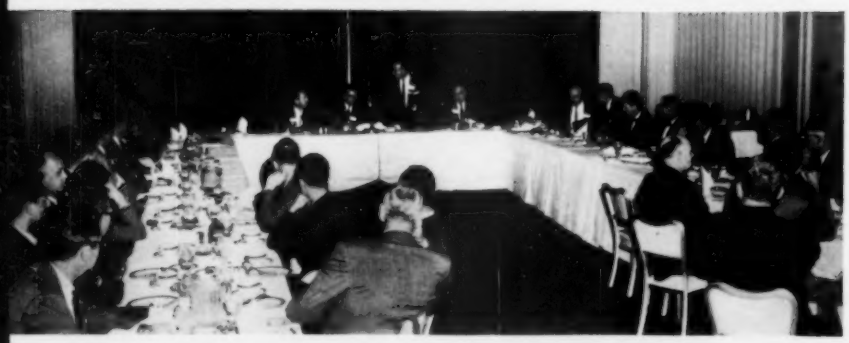
Greeting the opening session is E. K. Timby, a director of the American Society of Civil Engineers

B. G. Johnston, chairman of the Column Research Council of the Engineering Foundation addresses the opening meeting

The Society for Nondestructive Testing was represented by their President, D. T. O'Connor

The keynote speaker, C. M. Parker, vice president of the American Iron and Steel Institute, cited recent advances in steel technology

Opening session reveals a large and attentive audience



Authors' breakfast meeting finds B. E. Rossi, Welding Journal editor, showing the ropes to his successor, T. P. Schoonmaker

Keynote Address by Parker

The keynote address was given by Charles M. Parker, vice president in charge of research and technology, American Iron and Steel Institute. Choosing for his title, "Steel: Avant Garde," Mr. Parker described many aspects of pioneering leadership in the development of steel technology as it exists today. He went on to tell how the various engineering and technical societies helped to consolidate these developments and increase their usefulness to society.

Technical Sessions

In all, a total of 50 papers were presented in 17 sessions held Monday through Thursday. Four sessions—12 papers—were devoted to studies of welded structures both from the research and the application viewpoints. These sessions were sponsored by the American Society of Civil Engineers and two of them were co-sponsored by the Column Research Council. Their significance lies in the fact that the modern approaches—plastic design, higher strength, lower weight, tests on welded designs—are coming to rely more and more on welding. Other sessions included one sponsored by the Society for Nondestructive Testing, two on research and weldability and one each on resistance welding, brazing, electrodes and techniques, processes, rebuilding and surfacing, missiles, cutting, aluminum, high alloys and fabrication of weldments The wide topical range is an indication of the extent to which the field of welding was covered in these discussions. Some of these original contributions have been printed in the pages of the WELDING JOURNAL but most of them will make their appearance in the next few months, depending upon their suitability for publication.

At one of the 50 technical sessions, P. G. Jonas makes a point on welding of high-strength steels for bridges. He and co-author J. L. Beaton are from California Division of Highways

A popular feature was the National Fall Luncheon. W. W. Sproul, Jr., Westinghouse Electric vice president, spoke on future construction in America. Seated next to him, left to right, are President Thomas, Vice-President Chouinard and National Secretary Plummer

At the Districts Council breakfast, Past-President C. I. MacGuffie holds forth

Vice-President J. H. Blankenbuehler addresses the Section Officers during their meeting

Committee Business Meetings

Throughout the week a number of important AWS councils and committees held business meetings to review work and to develop recommendations relating to SOCIETY matters. In general, these meetings culminated in a meeting of the Board of Directors held on the final day. On Monday, Sept. 26th, the Member Classes Committee and the Technical Council convened. On Tuesday, there was held the Districts Council Breakfast Meeting. On this day also, two open meetings of general membership interest were held covering topics of increasing emphasis in AWS affairs: education and promotion. Wednesday saw the breakfast meeting of the National Membership Committee which was followed by the Missiles and Rockets Welded Fabrication Committee and, later in the day, the Section Officers group. Other groups meeting during the week were: the Resistance Welding Manufacturers Association, the Ohio State University Student Alumni Dinner and the WRC Resistance Welding Research Committee.

National Fall Meeting Luncheon

An innovation was offered this year as a substitute for the more formal evening banquet. This was a noon-time luncheon held on Tuesday as a diversion from the more intense activities and an opportunity for all groups to get together informally. The speaker was W. W. Sproul, Jr., vice president, General Products Div., Westinghouse Electric Corp. He spoke on "The New Face of America," a most interesting description of future construction plans for this country. The luncheon turned out to be a complete success.

Ladies Enjoy Delightful Program

As to the distaff side, welding may well have its importance—but there are other things in life. That the other things can be enjoyable was amply proved on the itinerary arranged for the ladies on Monday, Tuesday and Wednesday. A coffee hour was held each morning prior to departure. On Monday morning, a tour took the group through the latest redevelopment areas in modern Pittsburgh and to some historical points of interest. Following a luncheon at the attractive LeMont Restaurant, the group spent the afternoon at the famous Heinz plant of "57 Varieties" fame. On Tuesday, the ladies boarded the *Gateway Clipper* for a 3-hour river cruise around the city and environs. On Wednesday, the many objects of interest visited included the Oakland Cultural, Medical and Civic Center, the Heinz Chapel, Nationality Rooms, Cathedral of Learning, Schenley Park Restaurant, Carnegie Museum and Phipps Conservatory in Schenley Park. Thursday was left open for personal choice.

Plant Tours

Affording members the opportunity of seeing first hand some of the industries for which the area is renowned, four plant tours were arranged for Wednesday and Thursday. On Wednesday morning, the plant of U. S. Steel's American Bridge Co. at Ambridge, Pa., was visited. Here were seen the facilities for handling some of the larger structural work of the country. The afternoon was given over to a tour of the Shippingport Atomic Power Station of the Duquesne Light Co. This power-generating station is famous as the first attempt at commercial atomic-power generation in the U. S. On Thursday morning, a group visited the New Kensington Works of the Aluminum Co. of America. Here was an impressive display of the use and the future of aluminum in many fields of engineering. Thursday afternoon completed the variety of industrial sites by taking in the Brackenridge Works of Allegheny Ludlum Steel Co., pioneers in the manufacture of stainless steels. The tours were well chosen, giving members a good picture of the scope of industry in the Pittsburgh area.

The AWS Board of Directors in full meeting makes an impressive array

D. P. O'Connor representing the Los Angeles Section receives from President Thomas the Neitzel Award for greatest numerical increase in membership

President's Address

On behalf of the members of the AMERICAN WELDING SOCIETY, I extend to our guests a most cordial welcome to this, our second National Fall Meeting. We are honored that you gentlemen of the Column Research Council, of the American Society of Civil Engineers, and of the Society for Nondestructive Testing have consented to join in our social and technical programs. Our societies have for many years collaborated in research, development and promotion of new techniques for bringing better and lower cost structures to the American scene. We trust these activities will continue, and will, in fact, increase because we are facing some serious economic challenges that will not be solved by anything less than closely working together.

We have an important task to perform. We have been sent here to search out new ideas, to exchange experiences, and to find solutions to baffling problems. The degree of excellence with which we perform our tasks this week and in the weeks and months to follow will be measured by the acceptance of American welded products in the world market place.

It is significant that our meeting is held in this city of Pittsburgh, the center of the greatest steel industry in the world. We have a special responsibility to this industry, from whose mills flow the raw material for over 95% of the country's welded structures. I shall therefore direct my remarks this morning to our obligations to this industry and to the American economy because the two are closely linked.

No one refutes that steel is basic to the American economy. Financial men consider the rate of steel production an economic barometer. Our political leaders regard steel production as the mainstay of our national strength. Strong though our nation is today, despite a production rate of less than 60%, how much stronger could we be if we maintained a rate of 80% of today's capacity, an output of over 115 million tons each year.

This, gentlemen, is our responsibility. Too often we are prone to complain of others' failures—our national leaders, our financiers, our economists, our attorneys or our doctors. Your and my obligations to this civilization in which we find ourselves, to this country to which we owe our allegiance, to this economy which provides our standard of living—our obligation is to place on our domestic markets and on the markets of the world welded products which meet the needs of people at prices competitive with those of other nations.

All too frequently we talk of the competitive price of steel in world markets. While there is no doubt severe pressure on the price of steel, the real problem facing United States' industry is the price of finished steel products. Who can deny the loss to our steel industry from the growing imports of foreign made cars? Who can deny the loss of exports of American products to Latin American countries by the tremendous growth in European exports to this former all-American market? Look what has happened, for example, to household appliances: One reliable source[1] reports that in 1946 Brazil imported 13,000 refrigerators and 1,000 washing machines, all from the United States; by 1956, the sales of these appliances had risen to 150,000 and 40,000, respectively, all from sources *outside* the United States. It is time for all of us to wake up to the fact that fabricated products from steel and other metals must be made more competitive or our basic metal industries will suffer, our standard of living will decline and our military strength will be impaired.

For years our friends across the waters have looked to this country for new ideas in the fabrication of metals. This has been particularly true of the welding developments and methods during the past twenty years. Scientific teams visited our country in huge numbers during the decade following World War II, noting our high production methods of submerged arc welding, our new gas-shielded welding processes, our electrodes for welding joints in gas pipelines, our flash-welding techniques, our high-speed, fully-automatic resistance welding processes. These techniques which we used in the late 1940's and early 1950's meant that products which we turned out were clearly competitive in world markets, despite a tremendously higher hourly labor rate. But today, these low-cost production techniques, plus many developed there and not yet accepted by us, are being used by every industrial country of the world, and our former supremacy in productivity is rapidly being whittled away.

Those of us who have had the opportunity to visit in recent years the factories of West Germany, France, Belgium, England and other metal-fabricating countries, cannot help being impressed with the rapid acceptance of new tools which promise an increase in productivity. While we here in our many laboratories discuss endlessly the engineering features of new materials or processes, our competitors abroad have gone ahead and made use of them. Frequently they have introduced improvements and modification, which only become apparent during production use and

[1] Harvard Business Review, May-June 1959 p. 43.

The Neitzel award for the greatest percentage increase in membership was received by Z. Zabner on behalf of the Northwestern Pennsylvania Section

A group prepares to embark on one of the popular tours of the Pittsburgh area

The ladies had a fine time. Here a group enjoys the morning coffee-hour before departing on a sightseeing trip through Pittsburgh environs

At a luncheon just before the Meeting, the Pittsburgh Arrangements Committee checked final details with AWS personnel. The group responsible for the greatly successful affair included G. O. Hoglund, chairman, J. W. Kehoe, Hospitality, Signs and Technical; Mr. and Mrs. W. H. Kaufman, Ladies' Entertainment, K. H. Zeigler, Meeting Sessions; E. F. Davis, Plant Tours; H. E. Cable, Publicity

in this way are beginning to outstrip us in productivity, the one area of economic superiority which has been ours.

We need not become disheartened by foreign competitors. Competition has been the force which has made this country the industrial power that it is today. We need only to recognize our problem and take constructive action to deal with it.

Here are four specific steps requiring renewed concentration of effort:

Make our raw materials work harder—by more careful design and by use of alloy steels and other metals and alloys, we should be able to increase our stress allowances lighten our structures and reduce both raw material and transportation costs.

Increase the capability of our workmen for more welds and higher quality welds—by replacing obsolete welding methods, by designing for lower cost welds and by avoiding "over welding" we should substantially overcome the hourly wage handicap that we face from foreign competition.

Aim for multiple-unit production —wherever assembly-line techniques have been inaugurated, U. S. costs are hard to beat. In components for our heavy electrical or machine tool industries, usually requiring only one or two machines at a time, our competitors from abroad will invariably underbid us. A forceful world-wide marketing program of standardized machines produced by assembly-line methods could be the salvation of these U. S. industries.

Reduce costly inspection procedures—let's wake up to the basic principle that men and machines, not inspectors, determine the quality of the output and place our concentrated efforts on eliminating the cause of defects. Codes and other inspection standards that are unnecessarily restrictive slow us down and raise our costs; these must be eliminated. When defects are virtually nonexistent, inspection by low-cost statistical methods can be relied upon to assure an acceptable level of quality.

We are gathered here this week to share the experiences of those who have had some startling success or some technological break-through. The time and effort which have gone into making this forum possible, the preparation of papers, the arrangements for plant inspections, the provisions for committee meetings can only be justified by the diligent pursuit and application of the new ideas which are offered.

This forum is evidence that the leadership of this SOCIETY is dedicated to providing the means by which you can make your contribution. I would like to repeat what I said earlier. We have an important task to perform. We have been sent here by our respective companies to search out new ideas, to exchange experiences and to find solutions of baffling problems. We have a specific obligation to our companies to perform these tasks. The degree of excellence with which we accomplish our mission will be measured by the acceptance of American welded products in the world market place.

Insofar as the efforts of the AMERICAN WELDING SOCIETY in general and this National Fall Meeting in particular can help American fabricators of welded steel products to improve their quality and reduce their costs, we shall be contributing to raising the output level of our steel industry and strengthening our economy, our standard of living and our way of life.

1961 Visit of IIW Arouses Interest

Extensive progress made by various European countries in the development and application of welding has been the subject of much recent comment. The part played in this progress by the International Institute of Welding, while not known exactly, is believed by many to be of first importance. In 1948 when the Institute was formed, welding progress stood at various levels as between countries; today, many of the countries, that were behind then, have caught up and many new developments have been introduced.

Whatever the magnitude of the contribution to welding, the leaders of the IIW believe that much of its success stems from a particular method of operation. Since the U. S. will be the host country for the Annual Assembly of the IIW in 1961 at New York City, information concerning this group is of increasing interest. Last month the JOURNAL carried a brief outline of the structure of the organization. Some of the basic policy and methods are reviewed herewith, the purpose being to show in essence rather than in detail how objectives are attained.

The Constitution of the IIW states its basic purpose: "to promote the development of welding by all processes." In order to be able to promote progress and at the same time avoid difficulties arising from competing commercial interests, the Constitution further states, "the Institute shall not engage in commercial or trade activities and in particular shall not concern itself with prices, wage rates, markets or agencies." To be disinterested is a firm policy that includes the duty of preventing the Institute from being used in the sense of gaining competitive advantages from its support. In this free atmosphere, international cooperation has responded generously.

Unlike other international organizations, the national groups comprising membership are not in themselves the productive units by which the work of the IIW is carried on. The basic unit is a working technical committee on which all countries are permitted representation. There are 15 such units designated as commissions, by number, as follows:

I. Gas welding and allied processes
II. Arc welding
III. Resistance welding
IV. Documentation
V. Testing, measurement, and control of welds
VI. Terminology
VII. Standardization
VIII. Hygiene and safety
IX. Behaviour of metals subjected to welding
X. Residual stresses and stress relieving
XI. Pressure vessels, boilers, and pipelines
XII. Special arc welding processes
XIII. Fatigue testing
XIV. Welding instruction
XV. Fundamentals of design and fabrication for welding

The commissions, which operate on a continuous basis, may draw upon any source that will cooperate in its work—individual experts, universities, companies, private or public groups—anywhere in the world. These commissions are further assisted by the active collaboration of the Scientific and Technical Secretariat which coordinates their work. The purpose of the secretariat, in this respect, is not only to avoid duplication of effort among the commissions but to allocate work on certain subjects to more than one commission and to draw conclusions of a general nature from the work of several. Policy matters regarding the relations between the IIW and outside organizations are transmitted from the councils through the secretariat to the commissions. In addition, the secretariat prepares "coordination reports" and convenes meetings of commission chairmen to insure that necessary liaisons are effected and to consider problems of coordination. In this way the commissions are enabled to operate as efficient international teams.

At each annual assembly of the Institute, the commissions file a report which is drawn up for publication and may subsequently be released as an official document. Official correspondence and the documents of the IIW are printed in French and English. In the course of work, a large number of individual reports are received by the commissions. A selected number of these are offered for presentation at a public session during each annual assembly.

In the forthcoming annual assembly, to be held in New York City, Apr. 11–19, 1961, the public session has been transferred to the AWS Annual Meeting which is being held April 17–21. By this special arrangement, AWS members and their guests will benefit from an unusual opportunity to learn about developments in welding abroad from their foreign colleagues.

AWS DIRECTORS-AT-LARGE

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	A. A. Holzbaur	Jay Bland	R. B. McCauley
	D. B. Howard	F. G. Singleton	John Mikulak
	J. L. York	C. B. Smith	E. F. Nippes
	W. H. Hobart, Jr.	J. R. Stitt	R. D. Stout

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AWS PAST-PRESIDENT DIRECTORS

C. I. MacGuffie G. O. Hoglund

To Authors . . .

January 15, 1961 is the closing date for abstracts for the 1961 AWS National Fall Meeting.

Philadelphia Section Sponsors Courses

For the past eight years the Philadelphia Section of the AWS has offered courses in welding at Drexel Evening College. An attempt is now being made to extend the courses to include advanced welding metallurgy and elementary welded design. A questionnaire is being circulated by the Section to prospective students and to employers in order to determine the extent of interest and need. The replies may affect plans for a future degree-offering program.

Welcome

• Sustaining Member

Effective Aug. 1, 1960:

Westinghouse Electric Corp.
4454 Genesee St., Buffalo 5, N. Y.

The West-Ing-Arc Department is engaged in the design, manufacture and marketing of welding equipment and related product lines, systems and services principled on the electric arc. In the technology of joining metals, Westinghouse research facilities are constantly working in the metallurgical as well as the electrical field. The present-day silicon rectifier-type welding machine, automatic welding equipment and dynamic reactor are some of the outstanding West-Ing-Arc achievements.

All types of industrial a-c and d-c welding machines as well as larger sources of power and automatic equipment are assembled at Buffalo, N. Y., the department headquarters. A modern plant in Montevello, Ala., produces covered electrodes and brazing materials. Westinghouse relies on distributors for the marketing of the great majority of West-Ing-Arc products, and supports them with a specialized field selling force.

Sustaining Member Representative—F. D. Brown.

UNITED ENGINEERING CENTER

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	125	Dayton	100
Mahoning Valley	113	Holston Valley	100
Hartford	104	Long Beach	100
Kansas City	102	Louisville	100
Northeastern Tennessee	102	N. Central Ohio	100
Puget Sound	102	Olean-Bradford	100
Colorado	101	Pascagoula	100
Baton Rouge	101	Sangamon Valley	100
Niagara Frontier	101	Santa Clara Valley	100
Providence	101	Syracuse	100
Rochester	101	Toledo	100
St. Louis	101	Western Mass.	100
Boston	100	Wichita	100
Bridgeport	100	Worcester	100

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Detroit	$ 30	South Florida	$ 395
Philadelphia	82	Madison	400
Northern N. Y.	85	Richmond	400
Mohawk Valley	100	San Antonio	400
Tri-Cities	100	Western Michigan	400
Nashville	145	York-Central Pa.	435
Albuquerque	150	Cincinnati	438
Anthony Wayne	150	Saginaw Valley	466
Chattanooga	190	Salt Lake City	480
Shreveport	195	Portland	485
Arizona	200	Indiana	490
Eastern Illinois	200	Stark Central	495
Nebraska	200	Fox Valley	500
New Hampshire	200	Washington, D. C.	500
Maryland	215	North Texas	585
New York	218	Lehigh Valley	725
Carolina	245	Columbus	790
Northwestern Pa.	280	Long Island	800
J. A. K.	295	Northwest	822
Tulsa	295	Milwaukee	997
Iowa	300	San Francisco	1154
Michiana	300	New Jersey	1460
Mobile	300	Houston (and Sabine)	1540
Peoria	340	Chicago	1640
Birmingham	355	Pittsburgh	2168
Susquehanna Valley	355	Cleveland	2355
San Diego	365	Los Angeles	2825
Iowa-Illinois	370		
New Orleans	390		

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Paid herewith $_____ Balance will be paid as follows

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KEEPING YOU POSTED

by Fred L. Plummer

● Chairman J. E. Dato has completed organization of the Arrangements Committees for the 1961 Assembly of the International Institute of Welding which together with the AWS Annual Meeting and Welding Exposition will be held in New York during the period April 10–21. Vice Chairmen of the Long Island, New Jersey and New York Sections have accepted important assignments. Committee chairmen include the following: Ladies Program, H. C. Cook and J. W. Flannery; Plant Tours, E. W. Moles; Hospitality—Technical—Signs—President's Reception, H. D. Landis; Meeting Sessions, J. Mikulak; Publicity, A. V. Scherer; Banquet, M. J. Giraldi; Secretary, H. C. Phelps.

● This group met in your Secretary's office September 8th to receive reports of earlier meetings and complete all preliminary plans for the combined events which will bring together outstanding engineers, scientists, educators and industrialists from all major countries to exchange information concerning welding. The programs will be exceptionally interesting and informative.

● On August 31st Chairman H. E. Miller and Vice-chairman A. C. Axtell met with your Secretary and Assistant Secretary F. J. Mooney to plan for membership promotion and service during the next two fiscal years. The addition of a new staff member will enable Mr. Mooney to devote more of his time to these activities. The National Membership Committee will meet during the AWS Fall Meeting in Pittsburgh before these notes are published.

● During early September your Secretary met several times with Past-president C. I. MacGuffie, now closely associated with Past-president J. H. Humberstone who is organizing industry support for the IIW Assembly.

● Past-president J. J. Chyle visited headquarters on September 9th to discuss several activities including those of the Sustaining Member Committee of which he is chairman.

● In spite of rain and winds accompanying Hurricane Donna, Past president H. W. Pierce and President R. D. Thomas, Jr., came to New York from the Philadelphia area on September 12th to join Past-presidents O. B. J. Fraser and C. I. MacGuffie and Treasurer H. E. Rockefeller for meetings of the Reserve Funds Committee and a special Pension Committee which is studying insurance, pension and other "fringe benefits" which are or may be made available to your headquarters staff members.

● Hurricane Donna delayed but did not prevent the late evening departure by auto of Mrs. Plummer and your Secretary for Hershey, Pa., where the Arc Welding Section of NEMA was holding its annual meeting. During the next two days, in response to invitations from Chairman R. T. Brown and Secretary T. J. Ryan, your Secretary and AWS President R. D. Thomas, Jr., discussed SOCIETY organization and activities, and explored means of achieving the most effective relationship between the two groups. Discussions were productive and will aid in establishing closer cooperation and liaison in dealing with matters of mutual interest. Your Secretary was pleased to receive an invitation to attend future meetings of this important industry group.

● The following day, September 15th, President Thomas and your Secretary met with Rear Admiral E. H. Thiele, Engineer-in-chief, U. S. Coast Guard and Chairman of the Ship Structure Committee of the National Research Council in Washington. Following dinner with members of the AWS Washington Section, your Secretary discussed SOCIETY activities and President Thomas presented an excellent technical talk dealing with "Some Dramatic Applications of Stainless and Low Alloy Steels." Section Officers R. E. Lyons, John Huminik, Jr., W. P. Douglas and R. E. Letner conducted the carefully planned, well attended and accurately timed meeting which closed with a spirited discussion period. Several past chairmen, including C. A. Loomis who is now conducting an active membership drive, were in attendance as well as your Group insurance Trustee H. L. Ingram and other prominent members of this SECTION.

● September 19th and 20th were the dates when almost 300 eastern Zone members of NWSA met in New York for "Buzz Sessions" devoted to "sales" problems of importance in their businesses. Following brief talks on specific subjects by carefully selected speakers, the members in small groups, seated around tables, discussed each subject and then reported their best ideas to the entire group. NWSA President V. B. Anderson, Vice-president T. B. Quinn, Executive Secretary R. C. Fernley and AWS President R. D. Thomas, Jr., were among the speakers. Your Secretary was pleased to greet and discuss plans with NWSA Past-president A. C. Axtell, IIW Canadian Council Chairman R. A. Dunn and many other AWS and NWSA members.

● AWS Staff Members held a surprise luncheon for Welding Journal Editor B. E. Rossi on September 21st prior to his assuming the leadership of the Society for Experimental Stress Analysis on October 1st.

● The annual meetings of the divisions, executive committee and main committee of the Pressure Vessel Research Committee of WRC were held September 21st to 23rd at the call of Chairman I. E. Boberg and WRC Director Ken Koopman. Division Chairmen Downs, Lytle, Schreiner and Executive Secretary C. F. Larson assisted in conducting the various meetings.

● Following the writing of these notes AWS members will gather in Pittsburgh for the National Fall Meeting, reported elsewhere in this issue of the JOURNAL.

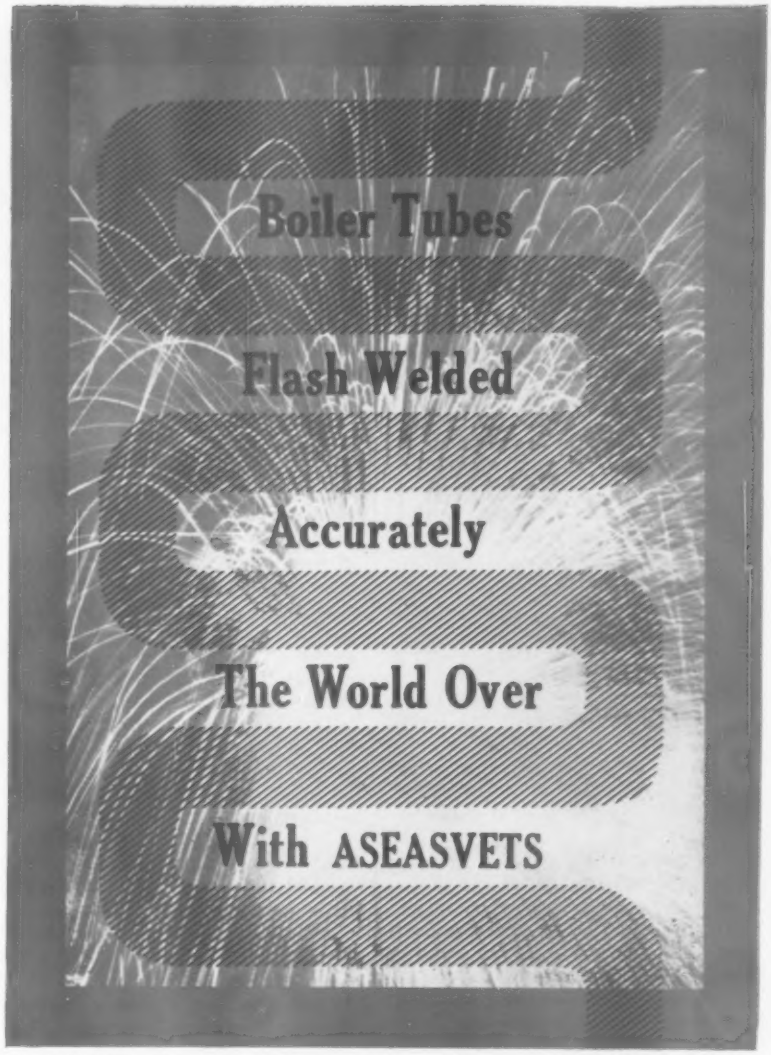
● During November President Thomas and your Secretary will meet with AWS Sections on these dates: 3, Schenectady; 8, Birmingham; 9, Cleveland; 11, Detroit; 15, York; 18, Baltimore; 21, Philadelphia and 22, Cincinnati.

● Active AWS member H. A. Sosnin of Jenkintown, Pa., has announced his availability as a consultant to producers and users of pipe and piping components.

Who's who?

The Who's Who in Welding read* THE WELDING JOURNAL. *The Journal is required reading for more than 50,000 potential buyers . . . key men in their respective fields . . . representing the largest concentration of purchasing power in the metal-fabricating world.*

** These are the people who buy and influence buying of welded products.*



The ASEASVETS Tube Flash Welder, world renowned for accuracy, includes automatic internal flash and upset reduction in preformed tube elements. Elements with tube spacings down to ½ inch can be welded. The ASEASVETS Boiler Tube Welder takes M.S., Cr. Mo., Stainless Steel and many others. Welders are complete with hydraulic clamping equipment, motor operated pre-heating, flashing and upsetting. Maximum welding surface up to 6 sq. in.; max. clamping force 30 tons; max. upsetting force 20 tons; max. O.D. up to 7". Also from ASEASVETS: Chain Welders—complete mills or individual units. Seam Welders—foot and air operated machines for steel, stainless steel or non-ferrous metals. Projection Welders—for production welding of small and medium sized parts. Spot Welders—highly economical for materials usually soldered or riveted. Resistance Heaters—for bolt blanks. Electrodes—Ordinary electrodes and electrodes with unusually deep penetration. Send coupon for free literature.

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EDUCATIONAL ACTIVITIES

EAC to Offer Course on Pipe Welding

The AWS School of Welding Technology has tentatively scheduled its third course of the 1960–61 series for Feb. 6–10, 1961, in New York City. In this course, the fifth since the program was begun, pipe welding will be the subject of lectures and discussions. During this course, a unique feature will be introduced: the text to be used will actually be a *preprint* of a chapter from the yet unpublished Section 5 of the *Welding Handbook*.

The course is part of a series of courses for graduate engineers on specialized welding subjects which will provide sufficient authoritative information for the engineer to gain a working knowledge of the subject. Planned by the AMERICAN WELDING SOCIETY to fill the need to keep abreast of the trends and developments in our rapidly changing technological world, these intensive courses have met with overwhelming response.

Designed to assist engineers whose companies wish to make use of the latest techniques in pipe welding, the course will cover three important areas. It will first consider the best applications for oxyacetylene, gas shielded-arc and shielded metal-arc welding techniques, both manual and automatic. The second area to be discussed will concern the welding of piping made of various steel alloys, stainless steel and aluminum and copper alloys. Finally, the course will consider design problems. As time allows, discussions on special uses of pipe and pipe welding will be held.

The faculty for the third AWS School of Welding Technology is being assembled. A prospectus and enrollment forms are available from the Secretary of Information and Education. As in prior courses, admission will be limited to fifty persons.

Section's Day Meeting Held in Pittsburgh

September twenty-seventh was devoted to the first AWS all-day meeting designed to assist Section Chairmen in using the basic techniques of Section education and publicity. Held in the Sky Room of the Penn-Sheraton Hotel, Pittsburgh, and presided over by E. C. Miller, Chairman of Publicity Committee, the well-attended meeting consisted of informative talks and lively discussions of proved methods for making educational and publicity activities more effective.

The morning meeting, entitled "Education Is Your No. 1 Project," began with a brief address of welcome by AWS President R. David Thomas, Jr. Chairman Miller then enumerated the educational material now available at headquarters and the additional material now in preparation. Expert advice on the holding of a two-day meeting was given by I. S. Goodman, who commented on the need for careful organization in order to ensure success. After an open discussion in which members of the audience added their experiences to those of Mr. Goodman, Ray F. Hoefler spoke on the conducting of an educational course and the best methods to use for success in both subject matter and attendance. A second discussion period and a question period concluded the formal morning session, but the ideas generated continued to form the subject of conversation during luncheon.

The publicity and promotion half of the meeting began in the afternoon with an introduction by R. E. Lawson on the problems facing a Section Publicity Chairman. R. V. McGahey spoke on the value of publicity, discussing the mechanics of publicity and giving examples of integrated programs. His comments were seconded by A. L. Phillips, Secretary of Information & Education, who pointed out that the National effort would be 83 times as effective if it were used by the AWS Sections as part of their local effort.

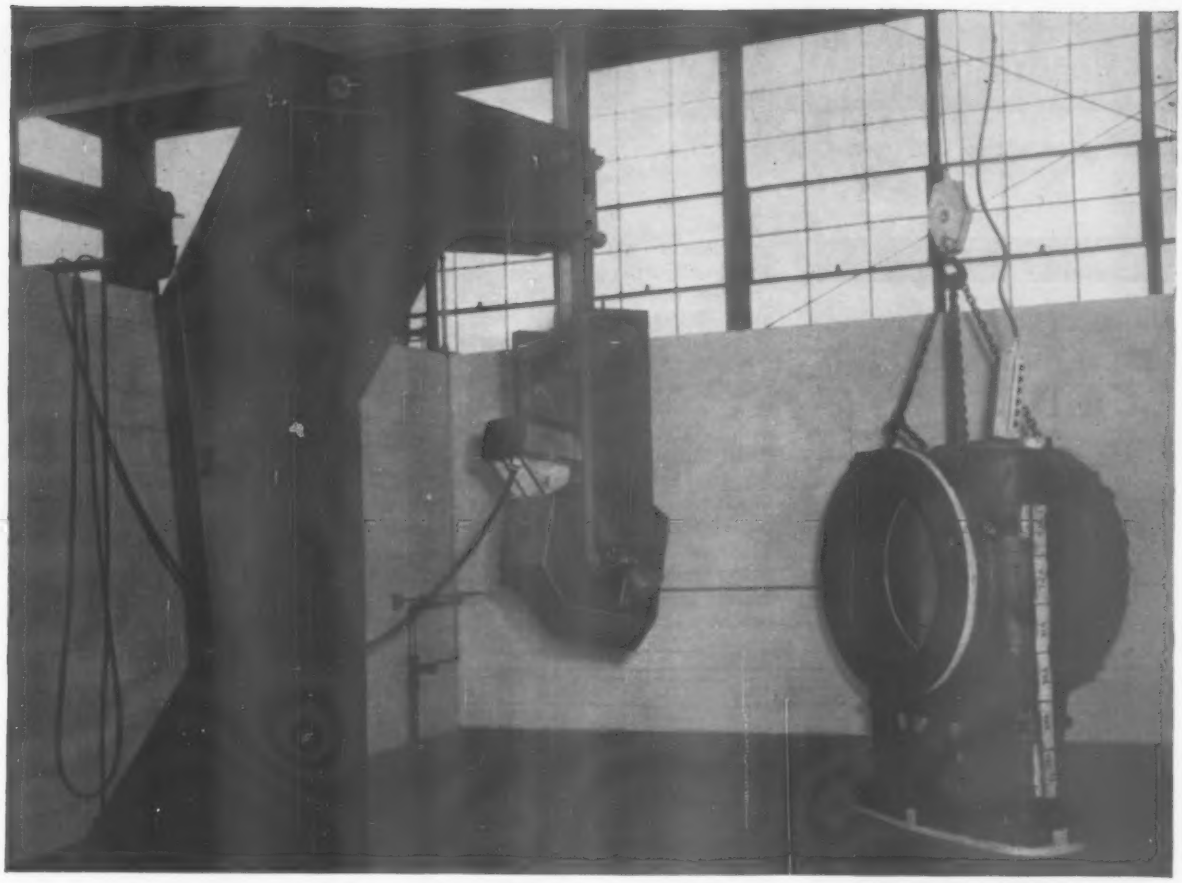
"Publicity at the Local Level" was the subject of a talk by Chairman Lawson, who distributed a Publicity Kit which covered Section News, local channels of communication, techniques for promoting National Welded Products Month and the gaining of local commercial and industrial cooperation. (Additional copies of the Publicity Kit are available from the Information Center at National headquarters.) Mr. Phillips developed Mr. Lawson's remarks further with a discussion of news releases, giving the formula for preparing releases that end up in print. An open discussion and question period that generated great interest followed. A panel of experts, consisting of the speakers and F. X. Neary, M. D. Bellware and W. H. Hobart, Jr., answered a variety of questions from the floor and clarified many of the techniques which had been discussed earlier. The meeting concluded with a rousing talk by Frank X. Neary entitled "Don't Underestimate What *You* Can Do," in which he provided additional "know how" for the Section's obtaining of coverage in newspapers, radio and TV, and for the gaining of commercial and civic support.

AWS School of Welding Technology

Five-day Course on Pipe Welding

Location:		New York City.
Date	:	Feb. 6–10, 1961 (tentative).
Fee	:	$75.
Who	:	The course is designed to assist the needs of the engineer whose company wishes to make use of the latest developments in pipe welding.
Why	:	To give him a grasp of the metallurgical considerations involved in the welding of ferrous and nonferrous piping and to introduce him to applications and design considerations.

Enrollments are limited to fifty and lists will be closed immediately after fifty applications have been accepted. Plan to attend this course and take advantage of the latest and most authoritative information on pipe welding techniques. Send for prospectus and application form, by addressing Arthur L. Phillips, Secretary, Information & Education, 33 W. 39th St., New York 18, N. Y.



A Model 1061 Multitron radiographing a large steel valve casting at Pacific Southern Foundries, Inc., Bakersfield, California, a subsidiary of Pacific Valves, Inc., Long Beach, California. Model 1061, a 1000 curie-cobalt 60 source, features fully automatic fail-safe protection and remote operation from a console control center. The special mounting stand was designed and fabricated by Pacific Southern Foundries, Inc. and Pacific Valves, Inc.

SAFE!... Budd Multitron® and Iriditron® Units for Gamma Radiography

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SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

California

AIR POLLUTION

Los Angeles—The *Los Angeles* Section held its first meeting of the 1960–61 fiscal year at the Rodger Young Auditorium on Thursday evening, September 15th with approximately 60 members and guests in attendance. The program for the evening began with a social hour followed by a dinner meeting.

Chairman - elect John Wiley opened the meeting with the introduction of his newly-elected officers as follows: Al Collins of Kaiser Steel, Chairman, absent due to business obligations; Orville Eichman, NCG, Secretary, and Leo West, Douglas Aircraft, Long Beach Division, Treasurer.

Speaker for the evening was Fred Reicher, member of Kaiser Steel's Public Relations, who presented "Air Pollution—Everyone's Problem," a picture produced by Kaiser Steel's own Cinematography Department, which won first place in National Film Producers Competition held in April 1959. The Kaiser Steel Co.'s interest in the problem of air pollution in the Southern county's area has been such that they maintain a technical staff, constantly working on the development through research to eliminate the eye irritating hazard commonly known as "smog."

Following this presentation, a picture in color, entitled "Steel Spans the Chesapeake" was shown through the courtesy of Bethlehem Steel Co., an amazing picture on present-day structural problems.

LOS ANGELES BEGINS NEW SEASON

Chairman-elect John Wiley opens September 15th meeting of the Los Angeles Section

Guest speaker Fred Reicher of Kaiser Steel Co. discusses air pollution

EXECUTIVE COMMITTEE OF SAN FRANCISCO SECTION MEETS

The Executive Committee of the San Francisco Section met on August 8th to discuss plans for the 1960–61 Section activities. Among those present were, left to right, L. Tinnes, F. Edises, Tom Hazlett, F. Stettner, W. Doherty, W. Ajello, A. Locke, C. Cummings, R. McCormick and E. R. Babylon

Florida

SUMMER MEETINGS

Miami—The *South Florida* Section held summer executive board dinner meetings. Wives of the members were invited and many attended.

The newly elected officers for 1960–61 are as follows: chairman, Harold Hose; first vice-chairman, Charles Hamburger; second vice-chairman, Bill Bushman; treasurer, J. W. Gundrum; and secretary, Bill Floroplus.

A very active fall and winter schedule has been planned by Program Chairman Perry Kennerk.

Illinois

PIPE WELDING

Joliet—The *J. A. K.* Section held a dinner meeting on September 8th at Tony D'Amico's in Joliet. Bill Lilly of Certified Welding Laboratories gave an excellent talk on testing welders for construction jobs. A question and answer period followed the talk.

METHODS ENGINEERING

Decatur—Donald E. Cox, chief industrial engineer for methods and processing of the Milwaukee Plant of the Caterpillar Tractor Co., addressed the September 13th meeting of the *Sangamon Valley* Section on the subject of "Methods Engineering as Applied to Arc Welding." The meeting was held at the Blue Mill Restaurant in Decatur.

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For details, circle No. 10 on Reader Information Card

SECTION MEETING CALENDAR

NOVEMBER 1

TULSA Section. "Power Sources for Arc Welding," J. H. Blankenbuehler, Hobart Brothers Co.

NOVEMBER 2

SUSQUEHANNA VALLEY Section. "Welding of Aluminum," A. Pfluger, ACF Industries.

NOVEMBER 3

CHICAGO Section. Calumet Area Meeting. Jockey Club Restaurant, East Chicago, Ind. Social 5:30. Dinner 6:30. Meeting 7:30. "Fundamentals of Arc Welding Electrodes," G. E. Claussen, Arcrods Corp.

NORTHERN NEW YORK Section. Hot Shoppes, Route 9, Albany, N. Y. Dinner 7:00 P.M. Technical Session 8:00 P.M. National Officers Night. National Secretary F. L. Plummer. "Electroslag Welding," by R. D. Thomas, National President.

NOVEMBER 7

NORTHWEST Section. University of Minnesota. One day seminar, "Identification and Prevention of Metal Failures in Welding."

NOVEMBER 8

BIRMINGHAM Section. Salem's Restaurant Number Two. "Some Dramatic Applications of Stainless Steel & Low Alloy Steel Welding," R. D. Thomas, Jr., Arcos Corp.

IOWA–ILLINOIS Section. Joint Meeting ASM, Hotel Blackhawk, Davenport, Iowa. Speaker C. E. Jackson, Linde Co.

WESTERN MASSACHUSETTS Section. Joint meeting with the Connecticut Valley Chapter of the American Society of Safety Engineers, Oaks Inn, Springfield, Mass., "Safety of Gas Welding and Cutting Equipment," Paul Croteau, Smith Welding Equip. Corp.

NOVEMBER 9

NORTH TEXAS Section. Howard Johnson's Turnpike Restaurant, 6:30 P.M. Speaker T. McElrath, Linde Co.

NOVEMBER 10

IOWA-ILLINOIS Section. Joint meeting with ASM. Blackhawk Hotel, Davenport, Iowa. Dinner 6:30 P.M. Meeting 7:30. Speaker Clarence E. Jackson, Linde Co.

JOLIET, AURORA, KANKAKEE Section. Aurora. "Hard Surfacing," C. Conley, Arcos Corp.

ST. LOUIS Section. Ruggeri's Restaurant. "It Isn't Mud," H. F. Reid, McKay Co.

NOVEMBER 11

COLUMBUS Section. "Resistance Welding."

DETROIT Section. Engineering Society of Detroit (Rackham Bldg.), 8:00 P.M. "Society Activities," National Secretary F. L. Plummer. "Some Dramatic Applications of Stainless and Low-alloy Steel Welding," President R. D. Thomas.

SANGAMON VALLEY Section. Decatur, Ill. "Which Welding Power Source Should You Buy," C. A. McClean, Air Reduction.

NOVEMBER 15

MOBILE Section. Korbet's Restaurant. 6:30 Social Hour; 7:15 Dinner, 8:00 Technical Session.

NORTHEAST TENNESSEE Section. Dinner Meeting; Social Hour 6:30 to 7:00 P.M., Dinner 7:00 P.M., Technical Session 8:00 P.M.

NOVEMBER 16

FOX VALLEY Section. 7:30 P.M., Appleton Elks Club, Appleton, Wis., "Welding of Cast and Ductile Iron," L. M. Petryck, International Nickel Co.

HOUSTON Section. "Pipe Welding Applications," Helmut Thielsch, Grinnell Co.

PEORIA Section. Vonachen's Junction. "Semi-Automatic Innershield Welding," Al Patnick, Lincoln Electric Co.

NOVEMBER 17

BEAUMONT Section. "Pipe Welding Applications," Helmut Thielsch, Grinnell Co.

MADISON Section. Beloit, Wisconsin. "Welding of Cast Iron & Ductile Iron," L. M. Petryck, International Nickel Co.

WASHINGTON Section. Auditorium of Washington Gas Light Co., "Welding of the World's Largest Undersea Craft, The Atomic Submarine Triton," Nino Pompilio, Electric Boat Division, General Dynamics Corp.

NOVEMBER 18

INDIANA Section. Buckley's, Cumberland, Ind., "Electron Beam Welding," Robert Banks, Airco.

MARYLAND Section. Chairman's Night, R. D. Thomas, Jr., and F. L. Plummer.

MILWAUKEE Section. Ambassador Hotel, 6:30 Buffet Dinner, 8:00 Technical Meeting., "Resistance Welding Applications at Western Electric Hawthorne Works," J. D. Eyestone, Western Electric Co.

NOVEMBER 19

PITTSBURGH Section. "Present Day Trends in Manual Electrodes," E. H. Turnock, Westinghouse Electric Corp.

NOVEMBER 21

HOUSTON Section (Corpus Christi Division). "Welding Metallurgy." Bob Anderson, Consulting Metallurgical Engineer.

PHILADELPHIA Section. "Electro-slag Welding," R. D. Thomas. F. L. Plummer, Coffee Speaker.

ROCHESTER Section. Liederkrantz Club, 8:00 P.M., Dinner 7:00. P.M. "Advances in Welding in Europe and Russia," Clarence E. Jackson, Linde Co.

NOVEMBER 22

SANTA CLARA VALLEY Section. Seballa's Restaurant. "Welding of Metals by Explosive Techniques," D. Davenport, Stanford Res. Inst.

NOVEMBER 29

HOUSTON Section (Austin Division). Villa Capri Restaurant. "Welding Inspection," Samuel Bryant, Shilstone Testing Lab.

NOVEMBER 30

NIAGARA FRONTIER Section. Dinner 6:45. Meeting 8:15. AMF Plant Tour.

DECEMBER 1

NORTHERN NEW YORK Section. Hot Shoppes, Route 9, Albany, N. Y. Dinner 7:00 P.M. Technical session 8:00 P.M. "Aluminum Welding: Past, Present and Future," Ivan MacArthur, Olin Mathieson Chemical Corp.

DECEMBER 3

PEORIA Section. Jobst Hall, Bradley University. ASM-AWS Educational Series 3 lecture, afternoon Symposium on "Cost Reduction."

SAINT LOUIS Section. Annual Ladies Night-Dinner and Dance. George Johnson's KMOX-TV Studio Orchestra, Norwood Hills Country Club.

DECEMBER 6

BIRMINGHAM Section. "Welding Problems in Steel Fabrication and their Solutions," D. J. Snyder, U. S. Steel Corp.

TULSA Section. Danner's Cafeteria, Tulsa, Okla. "Welding Metallurgy," Paul Ogden, Phillip's Petroleum Co.

DECEMBER 7

SUSQUEHANNA VALLEY Section. Foot Hills Manor, Shickshinny, Pa. Dinner 6:45 P.M. "Nondestructive Testing of Weldments," Warren J. McGonnagle, Argonne National Laboratory.

DECEMBER 8

IOWA-ILLINOIS Section. Highland Park Bowl, Moline, Ill. Dinner 6:30 P.M. Meeting 7:30 P.M. Film Show.

JOILET, AURORA, KANKAKEE Section. Joliet Cozy Cottage, Social Meeting.

DECEMBER 10

FOX VALLEY Section. Van Abel's, Hollandtown. Wis. Annual Christmas Dinner Dance.

DECEMBER 12

NORTHWEST Section. Annual Christmas Party.

DECEMBER 13

SANGAMON VALLEY Section. Springfield, Ill. "Some Welding Problems and Their Solutions and Distortion Control in Welded Structures," L. J. Larson, Allis-Chalmers.

DECEMBER 14

NORTH TEXAS Section. Howard Johnson's Turnpike Restaurant. Dinner and Technical Session 6:30 P.M.

DECEMBER 15

MADISON Section. Edgerton, Wis. "Joining of Super Alloys," Karl M. Weigert, Curtiss-Wright Corp.

DECEMBER 16

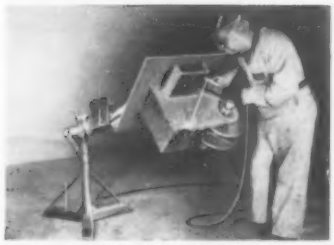
INDIANA Section. Chicken & Steak Restaurant, Shelbyville, Ind. Plant Tour of General Electric Plant.

MILWAUKEE Section. Ambasador Hotel, 6:30 Buffet Dinner; 8:00 Technical Meeting. "Method for Determining Expected Amount of Over-welding," O. Riteris, Bucyrus-Erie Co.

DECEMBER 21

PEORIA Section. Vonachen's Junction. "Open Flame Spray—Brazing with Powdered Metals," H. E. Miller, Carrier Corp.

Editor's Note: Notices for February 1961 meetings must reach JOURNAL office prior to November 20th, so that they may be published in the January Calendar. Give full information concerning time, place, topic and speaker for each meeting.



Aronson UNIVERSAL BALANCE Positioners
T.M. Reg. U. S. Patent Office
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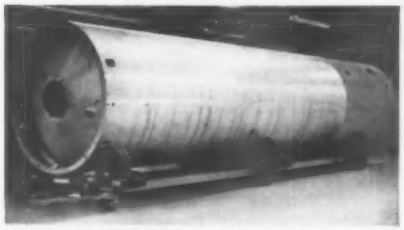

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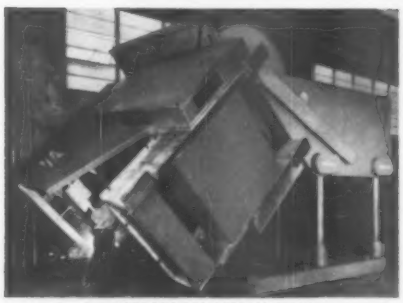

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Indiana

INDUSTRIAL TOUR

Niles—On September 15th, the *Michiana* Section opened its 1960–61 season with an industrial tour through the Tylor Refrigeration Corp., Niles, Mich., manufacturers of refrigerated display cases and walk - in coolers. While welding does not form a very large portion of their assembly procedures, the trip was most interesting, especially in the area where evaporator coils are made. Assembly of the fins was with a Tyler-designed automatic loader and spacer, a most ingenious machine. Since Tyler manufactures a strictly custom line of coolers, the visitors were able to see a wide variety of assemblies which are put together on an assembly line reminiscent of an automotive line.

Kansas

STAINLESS STEEL

Wichita—The *Wichita* Section enjoyed a semitechnical report on "How to Select the Right Welding Process for Stainless Steel"; which was very ably presented by Wayne L. Wilcox, products manager, Arcos Corp., Philadelphia, Pa.

Mr. Wilcox's talk was preceded by an informal dinner and social hour at the Stockyards Hotel. The speaker discussed the characteristics of the three fusion welding processes commonly used in stainless steel fabrication, and the response of each of the four general classifications of stainless to welding. The advantages and disadvantages of each process were pointed out.

Louisiana

HIGH-STRENGTH STEELS

Baton Rouge—Milton D. Randall, welding engineer, Metals Joining Division, Battelle Memorial Institute, started the *Baton Rouge* 1960–61 season on September 15th with an address on the "Welding of High-alloy and Low-alloy High-strength Steels." The presentation reflected a great need for close detail to all the elements of welding. In the advances of science, more stress is being placed upon high-strength materials requiring careful application of weld material. Most failures in high-strength welds have been

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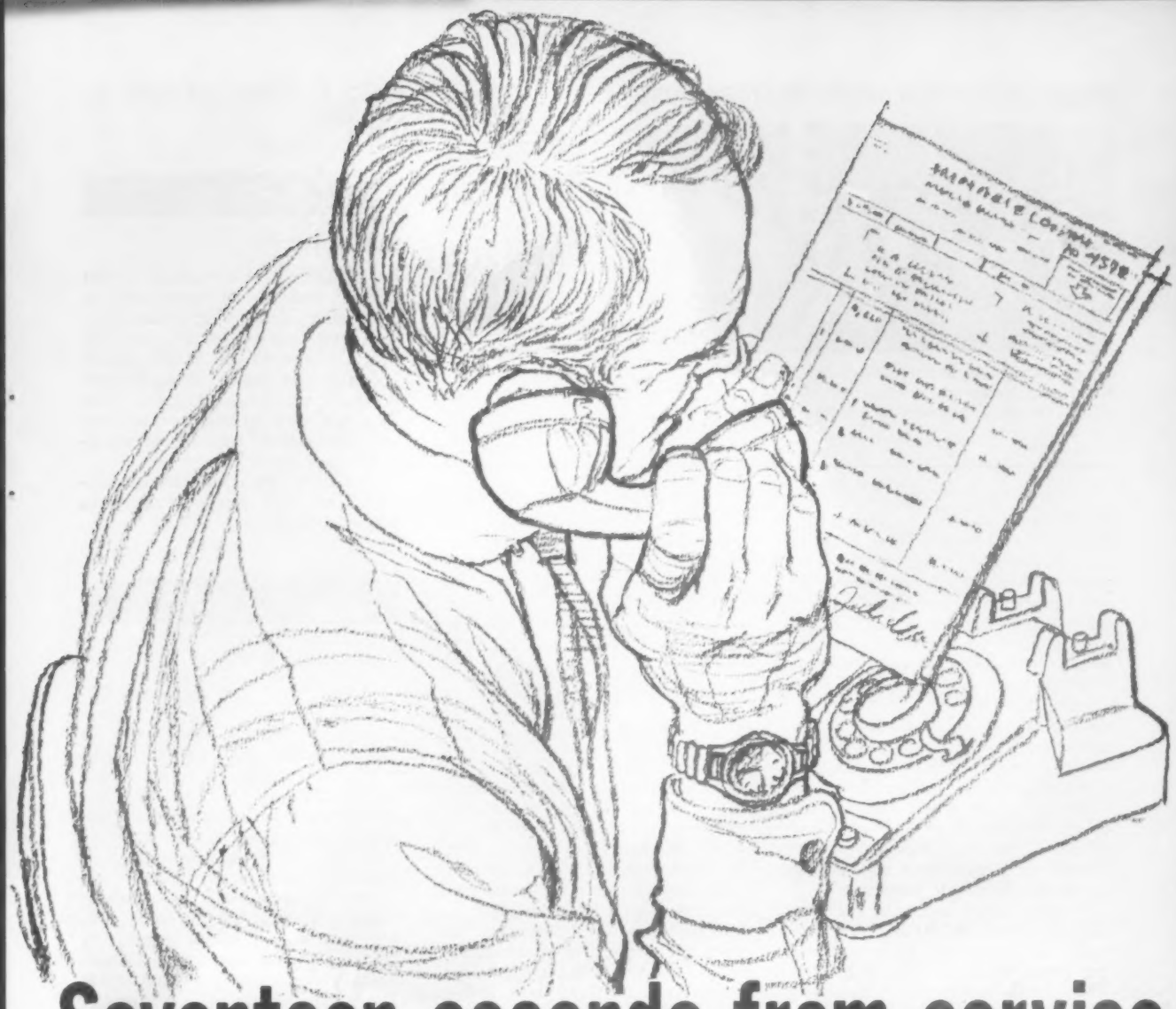

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MARYLAND SECTION TOURS WESTINGHOUSE

Shown are eighteen of the thirty-six Maryland Section members and guests who toured the Air Arm Division of the Westinghouse Electric Corp. at the Friendship International Airport on September 17th

found to be caused by hot intergranular cracking. These cracks are microscopic and cannot be detected through X-ray, magnetic particle, ultrasonic or dye penetrant inspection techniques.

The meeting was held at the Sherwood Forest Country Club and was attended by 36 members and guests. Also at this meeting, Robert Daniel and O. J. Templet were appointed co-chairmen for the high school science contest on subjects pertaining to the joining of metals. Winners will be given either a trip to the Welding Show in New York in April 1961, or like amount of money to apply to a scholarship of the selection of the winner.

It was announced that registration at Louisiana State University night school course on metallurgy has exceeded all previous estimates. The local newspaper in giving publicity to this course erroneously reported it was to be a course in welding. The University was swamped with telephone calls by operators seeking to receive advance instruction through the University and the local Section. This great interest is being studied by the Section Educational Committee to consider for possible future programs.

ELECTION OF OFFICERS

Baton Rouge—The *Baton Rouge* Section announces the election of the following officers for 1960–61: Chairman, Ed Edley, Nadler Foundry & Machine Co., Inc.; First Vice-chairman, M. V. Christesen, Delta Tank Mfg. Co.; Second Vice-chairman, Craig Kennedy, Air Reduction Sales Co.; Secretary, Gil Black, General Dynamics Corp.; Treasurer, Louis Mire, Ormet Corp. Executive Committee—Louis Bergeron, Rogert Daniel, O. J. Templet, Herbert Boxhill, Harmon Cutler, C. L. Paxton, and James M. Shilstone.

DETROIT PRESENTS AWARD AND HEARS GUEST

James C. Cox was presented with the George N. Sieger Award by R. B. Wilcoxson at the Detroit Section September 9th meeting. Left to right, above, are Ray Wilcoxson and James Cox

Bill Sheehan, News Editor for Station WJR, answers questions at the Detroit Section September 9th meeting concerning his experiences with President Eisenhower on a recent overseas trip

Maryland

PLANT TOUR

Baltimore—The *Maryland* Section held its annual fall plant tour on September 17th. Thirty-six members and guests toured the Air Arm Division of the Westinghouse Electric Corp. located at the Friendship International Airport. The tour was very interesting and very well conducted by the Westinghouse personnel.

A Dutch Treat lunch was enjoyed at the nearby Friendship Airport restaurant.

Michigan

EISENHOWER TRIPS

Detroit—A large number of *Detroit* Section members, with their wives, met on September 9th at Detroit's new and colossal Cobo Hall to present the George N. Sieger Award to James C. Cox. This annual award was bestowed in acknowledgment for the outstanding personal service and over-all contribution made by Mr. Cox.

Jim Cox, who has been in contact with Resistance Welding since 1915, has been a very active member of the Executive Board of the Detroit Section and is past president of the Resistance Welding Alloy Association. He retired this year from business having been president of S-M-S Corp. since 1953.

After enjoying the fellowship of a cocktail hour and a full course dinner, the audience was privileged to hear William (Bill) Sheehan, News Editor of WJR, the Goodwill Station, report on his behind-the-scenes experiences as he toured the United States with President Eisenhower and Khrushchev and also as he accompanied Mr. Eisenhower on his recent trip to the Phillipines, Korea, South America, etc.

DEFENSE FILM

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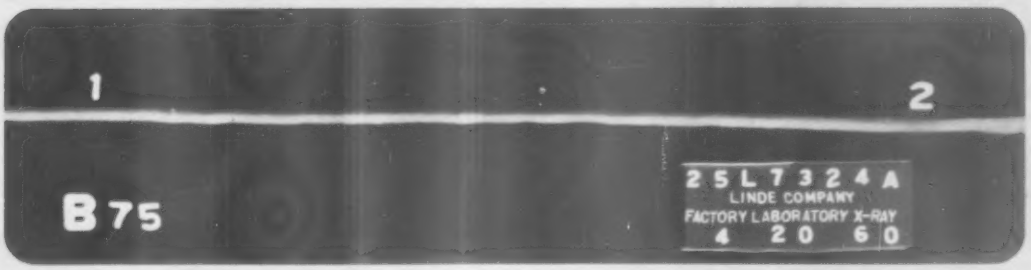

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NORTHWEST SECTION VISITS PLANT

Section members are shown at Rosemount Engineering Co. where they viewed an electron-beam welding machine (in background) in operation on September 12th

Defense" tells the story of this vital defense network.

At the September 14 meeting of the *Saginaw Valley* Section held at Hi-Life Inn, William C. Chesney, acting division plant staff superviror of the Central Division of Michigan Bell and responsible for all military installations, elaborated on the film and gave some pertinent facts on the part that Michigan Bell Telephone played in the construction of the SAGE system.

Minnesota

ELECTRON BEAM WELDING

Minneapolis—On September 12th, the *Northwest* Section opened its fall program with an outstanding meeting featuring the most recent contribution to the welding field—electron beam equipment. R. A. Stone, assistant sales manager, Special Products Dept., Air Reduction Sales Co., illustrated his talk with slides which described the concepts involved in the design and use of this equipment. Following this briefing 125 members and guests were taken on a tour of Rosemount Engineering Co.'s welding facility, where they were able to view an electron beam welder in operation, and also to examine other equipment in this extremely modern and well-equipped welding center.

Missouri

PLANT TOUR

St. Louis—Some 110 members and guests of the *St. Louis* Section

NEW YORK SECTION PRESENTS JOHN E. TAYLORSEN AWARD

On June 14th, two seniors from Polytechnic Institute of Brooklyn received awards for outstanding papers on welding. First prize of $200 went to Arthur Filippi; second prize went to Frank Longo. Left to right, above, are Section Chairman Dan Bellware, Prof. George Fisher, Section Treasurer Edward N. Madison, Arthur Filippi, and Educational Secretary Arthur L. Phillips

Tempilstik°. . . temperature indicating crayons

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NORTHEAST TENNESSEE SECTION BEGINS NEW YEAR

T. McElrath of the Linde Co. was guest speaker at the first meeting on September 13th. Left to right, above, are Frank Shattuck of the Tennessee Welding Supply Co., Section Chairman Peter Patriarca, T. McElrath, Section Technical Chairman G. M. Slaughter, and Section Program Chairman H. B. Harlan

visited the St. Louis Industrial Division of Combustion Engineering, Inc., on Thursday, September 15th. The members and guests were taken on an informative guided tour of the plant which included pipe bending, induction welding, CO_2 gas-flux welding, coated electrode welding, submerged arc welding, heat treating facilities and the finished product consisting mainly of packaged boilers.

New York

WELDING METALLURGY

Bellmore—To cover a subject as comprehensive as the "Metallurgical Principles of Welding" objectively in 90 min is a task few speakers dare to tackle. The *Long Island* Section was fortunate in having Ludwig Anselmini of the International Nickel Co., to do justice to this job at their meeting held on September 15th at Sunrise Village in Bellmore.

Using fundamental analogies such as the comparison of weld puddle solidification with "what part of the pot contains the coolest soup?", the phenomena of heat transfer, thermal expansion, crystal formation and growth, etc., were introduced and related to the common welding bugaboos such as porosity, distortion and residual stresses.

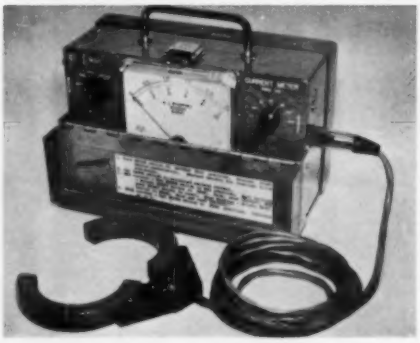
The interest of the audience in the presentation was evidenced by the enthusiasm shown in the lively question and answer period that followed.

Ohio

GUIDED TOUR

Columbus—A dinner meeting of the *Columbus* Section was held at the Riverside Rathskeller on September 9th. Following the din-

WANT TO MEASURE RESISTANCE WELDING SECONDARY CURRENT?



Battery powered, transistorized portable Model 260 meter measures true RMS value of secondary current for single phase welders used with or without heat control. Seven ranges to 250,000 Amps, ±3% accuracy, down to one cycle weld time, uses special air core toroid requiring no direct connection to welder.

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Authors...

please note!

All authors interested in presenting papers at the AWS 1961 Fall Meeting to be held in Dallas, Texas on Sept. 25–28, 1961 are advised that the usual forms, "An Invitation to Authors" and "Author's Application Form," were printed as a detachable insert in the October issue of the Welding Journal.

Additional copies of the forms may be obtained by writing to AWS Headquarters, 33 West 39th St., New York 18, New York.

WELDED STAINLESS INTERIOR— KEY TO VITAL HIGH-PURITY SYSTEM FOR DRESDEN REACTOR

43,000 pounds of stainless electrodes and wire protect nuclear system from corrosive impurities

Dresden Nuclear Power Station, near Chicago, is one of the first installations to use nuclear energy for commercial purposes. Vital to its operation is the maintenance of a high degree of water purity. The extensive use of stainless steel in the reactor keeps the unit as free as possible from corrosive elements which would lower this purity level.

The weld-clad interior of the reactor vessel required in excess of 43,000 pounds of stainless steel electrodes and welding wire. New York Shipbuilding Corporation, Camden, New Jersey, fabricators of the vessel, used ARCALOY Stainless Steel Electrodes for manual cladding and welded joints. Alloy Rods Company Bare Stainless Steel Welding Wire was used for submerged arc cladding.

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FOX VALLEY SECTION OFFICERS MEET

Among those who attended the August 24th dinner meeting of the officers and committee members of the Fox Valley Section were, left to right, Past-chairman J. Weigand, Chairman J. Teigen, Past-chairman M. Kern and Secretary R. Hart

ner meeting, the members and guests were taken on an interesting guided tour of Jeffrey Manufacturing Co. The tour provided an opportunity to see many diversified manufacturing facilities. A wide range of chains for elevating and conveying equipment, sprocket and idler pulleys, transmission machinery, and a variety of feeders, separators and crushers were seen being fabricated. Final assembly of special products which included drilling, cutting and conveying equipment for coal mining operations were seen.

The structural and welding shops were also included in the tour. Welding applications covering the use of metal arc, tungsten inert gas, metal inert gas, CO_2 shielded, and submerged arc on a broad range of materials were observed.

Pennsylvania

SOCIAL EVENT

Pittsburgh—In lieu of the usual technical meeting on September 13th, members of the *Pittsburgh* Section attended a baseball game between the Pittsburgh Pirates and the San Francisco Giants. Over 150 members and guests watched the hopeful Buc's retreat a step in the National League pennant race, the final score being Giants 6 and Pirates 3.

Tennessee

GAS-SHIELDED WELDING

Oak Ridge—The *Northeast Tennessee* Section started the year off with a bang at the new Holiday Inn on Tuesday, September 13th. Preceding the technical presentation, a round of good fellowship was enjoyed by members and guests.

Speaker for the evening was Tom McElrath, special project engineer, Development Laboratory, Linde Co., Newark, N. J.

Mr. McElrath's talk was divided into two sections—one on new developments in tungsten-arc welding, the other on new developments in the gas-shielded-arc consumable-wire welding.

Development of the tungsten-arc pilot-arc starting principle was described. This eliminates the false starts occasionally encountered with high-frequency starting and thus provides perfect and reliable starting of the arc. It has been successfully applied to spot welding and is being used on a fully automated tape-control machine involving the use of four torches. A 10-min sound movie showed this machine in action.

The Linde short-arc process was described as a combination of a new type power supply, wire feed and torch equipment for using 0.030 in diam wire for many metals, and a new argon–CO_2 mixture for welding steel. This process has proved uniquely successful for welding sheet metal as well as pipe and for filling gaps caused by poor fit-up. The process derives its unique advantages from the fact that the arc is actually going out many times a second. A 4-min high-speed motion picture illustrated this process in action.

Texas

AWS AIDS

San Antonio—The *San Antonio* Section held its annual membership

SUPPORT YOUR SOCIETY.....

.....BE ACTIVE!

drive meeting at the Lone Star Brewery on August 24th. Percy Pennybacker, past District No. 9 director, was the principal speaker to the 146 members, guests, and prospective members.

Mr. Pennybacker pointed out the many aids that are available to its members from the SOCIETY itself and pointed to the wealth of information and experience available through its Section members.

The September 6th meeting closely following the membership drive meeting was held at Cap't. Jim's. The program was a question - and - answer forum with a lively discussion on the welding of magnesium, cast and malleable iron, reject structural grade pipe and hard surfacing.

Wisconsin

WELDING OF TRITON

Madison—At a meeting of the *Madison - Beloit* Section held on September 15th, at the Eagles Club in Madison, George W. Kirkley, Jr., research and development engineer for General Dynamics Corp., Electric Boat Division, gave a talk on "Welding of Triton, World's Largest Nuclear - Powered Submarine." A copy of this paper was published in the September 1960, issue of the WELDING JOURNAL.

The *Triton* is the first ship in history to be propelled by twin nuclear power plants. It is the first submarine to be designed for three-deck levels within the hull. Another first on the *Triton* is a 40-line switchboard to monitors a dial telephone system throughout the ship.

Mr. Kirkley's talk dealt mainly with the welding and fabrication problems encountered in this nuclear-powered propulsion system. He also explained many proved techniques developed during the building of the first A-sub, Nautilus and subsequent ships. Particular emphasis was placed on the unique and unusual techniques that have been developed at Electric Boat Division for the welding of nuclear piping systems. Also included in the discussion were the welding problems and fabrication sequences associated with thick hull sides.

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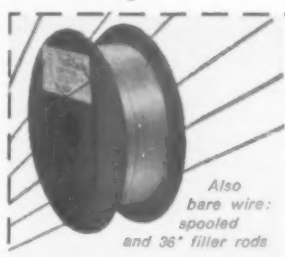

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To learn how an Aardvark licks termites... call in a *ZOOLOGIST*

(specialist on animals)

A native of Africa, the AARDVARK is a large, nocturnal, burrowing mammal subsisting largely on termites and has a long extensile tongue for gathering them. He has heavy claws for ripping open rotten logs to find more termites.

For details, circle No. 21 on Reader Information Car

To learn how to lick welding problems... call in *LINCOLN*

(specialists in arc welding)

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LINCOLN WELDERS

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New Members

EFFECTIVE SEPTEMBER 1, 1960

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Members

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	204
Members	6,405
Associate Members	5,644
Student Members	283
Honorary Members	10
Life Members	29
Total	12,575

AWS Builds Men of Welding

BOSTON
Carter, John S. (C)
Jefferson, Albert E. (B)

BRIDGEPORT
Kelsey, Joseph J. (B)

CANADA
Lachoski, Henry A. (C)
Lynam, G. P. (C)

CHICAGO
De Lucia, James (C)
Elliott, Edward (B)
Evans, Charles D. (B)

CINCINNATI
Bragg, Davis, A., Jr. (B)
Deane, Neil O. (B)
Hanna, Carl (C)
Leach, Austin F. (B)
Weitzel, J. Richard (C)

CLEVELAND
Fassinger, Charles R. (C)
Palovcik, John (B)

COLORADO
Roe, William E. (A)

DAYTON
Funk, Harold L. (B)

DETROIT
Doran, Frank (B)
Gardner, Ralph H. (B)
Grinstead, Laurence (C)
Lausten, Arthur T. (B)

FOX VALLEY
Weber, Ronald D. (C)

HARTFORD
Gere, Nathaniel S. (C)
Reynolds, Paul A. (C)

HOUSTON
Breining, Alfred P. (B)
Lee, Clyde W., Jr. (C)
Matlock, Charles S. (B)

IOWA
Nelson, G. A. (B)
Orin, C. Walter (B)

IOWA-ILLINOIS
Seaton, Richard (B)

KANSAS CITY
Schubert, Paul L. (C)

LOS ANGELES
Elliott, Edwin G. (B)
Forrest, Thomas A. (B)
Godward, Charles L. (C)
Ricci, Thomas (B)
Sherrick, E. T. (B)
Smith, Norman S. (C)
Tamiyasu, Mickey M. (C)
Von Schlegell, F. (C)
Woodbury, Roger K. (C)

MADISON
Krause, Lester D. (B)

MAHONING VALLEY
Bakich, Alexander (B)
Hillman, Lawrence G. (B)
Sant, John M. (B)

MARYLAND
Peterson, Jacque A. (C)
Steiner, Edward E. (B)

MILWAUKEE
McCaig, Le Roy F. (C)
Moecher, Dean P. (C)

NEW JERSEY
Brancato, Joseph J. (B)
Daly, James N. (C)
Farrell, Edward L. (B)
Love, James Holm (C)

NEW YORK
Schneebeli, Alfred A., III (C)

NIAGARA FRONTIER
Flanigan, Robert G. (C)
Tabraham, George L. (B)

NORTH TEXAS
McLeod, Dale K. (C)

NORTHERN NEW YORK
DeBoer, Samuel (C)
Wassell, Frank A. (C)

NORTHWEST
Van Sickle, Lois N. (C)

OKLAHOMA CITY
Johnson, C. E. (C)
Sherman, John C. (B)

ORANGE COUNTY
Boehles, John W. (B)
Dombroski, Walter A. (B)
Driscoll, Charles L. (B)
Fritts, William A. (B)
Kryder, Harold O. (B)
Laiola, Samuel J. (B)
Lohoff, Donald L. (B)
Maybee, James J. (B)
Mays, Herschil K. (B)
McMenamin, Albert (C)
Shuttleworth, J. H. (B)
Westholm, W. W. (B)

PEORIA
Edwards, Harper A. (C)
Fischbacher, Walter (C)
Garrison, William W. (C)
Geurin, J. H. (C)
McEndollar, Willard (C)
Scoggins, George (C)

PHILADELPHIA
Arnold, Henry A. (B)
Grigonis, George (B)
Lill, Joseph, Jr. (C)
Munch, Jacob Carl (C)

PITTSBURGH
Berger, J. Alfred (B)
Disque, Robert O. (C)
Dmitrzak, Stanley (C)
O'Mahoney, Charles J. (C)

PROVIDENCE
Dennett, William T. (C)

PUGET SOUND
Dohrer, R. L. (B)

RICHMOND
Freeman, Robert E. (B)

ROCHESTER
Dormer, George J. (C)

SABINE
Turner, Jack D. (B

ST. LOUIS
Day, Thomas W. (B)

SAN DIEGO
Clites, Wayne R. (B)

SANTA CLARA VALLEY
Gunn, Charles (C)

SUSQUEHANNA VALLEY
Stiner, David D. (B)

TULSA
Fairless, James C. (C)
Lewallen, H. R. (B)
Moss, Paul B. (B)

WESTERN MASSACHUSETTS
Barber, Leland M. (B)
Zeppieri, John D. (C)

WICHITA
Farabough, Herbert (C)

YORK-CENTRAL PA.
Hutton, Robert D. (B)

MEMBERS NOT IN SECTIONS
Cleaver, Victor M. (B)
Correa, Herman C. (B)
Kelly, William Trainor (C)
Kodama, Hajime (B)
Landaez, Alfonso (B)
Omori, Harry T. (B)
Oshita, Harry S. (B)
Pratt, John Leonard (B)
Rittenhouse, Raymond D., Sr. (B)
Schluter, Ricardo (B)
Takekawa, Herbert K. (B)
Toyne, Geoffrey (B)

Members Reclassified During September

CHICAGO
Dunne, John J. (B to A)

CLEVELAND
Cheng-Teh, Shen (C to B)

DETROIT
Singbiel, Richard (C to B)

HOLSTON VALLEY
Long, Laurence M. (C to B)

IOWA-ILLINOIS
Burgston, C. H. (A to F)

NEW YORK
Ryan, James F. (B to A)

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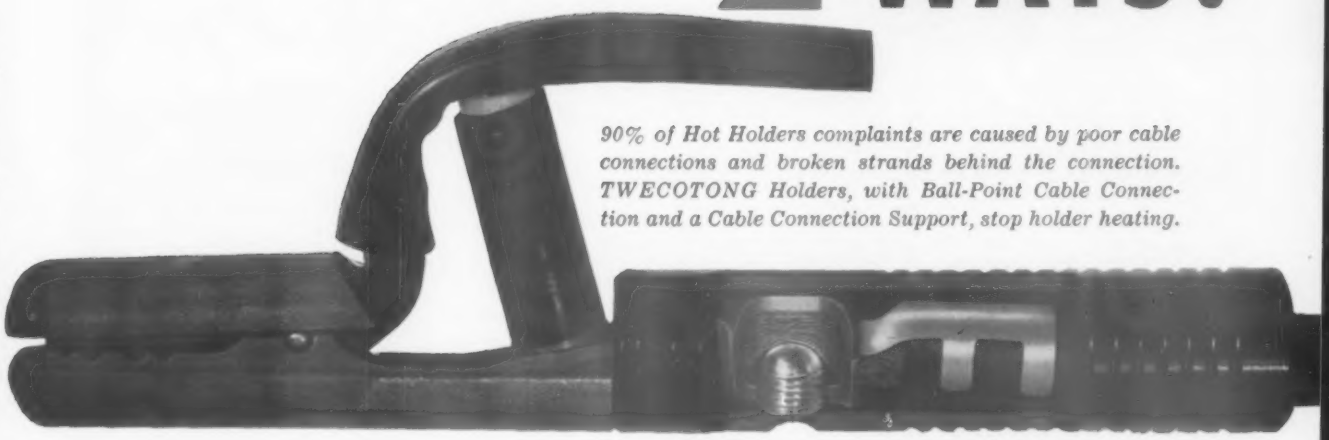

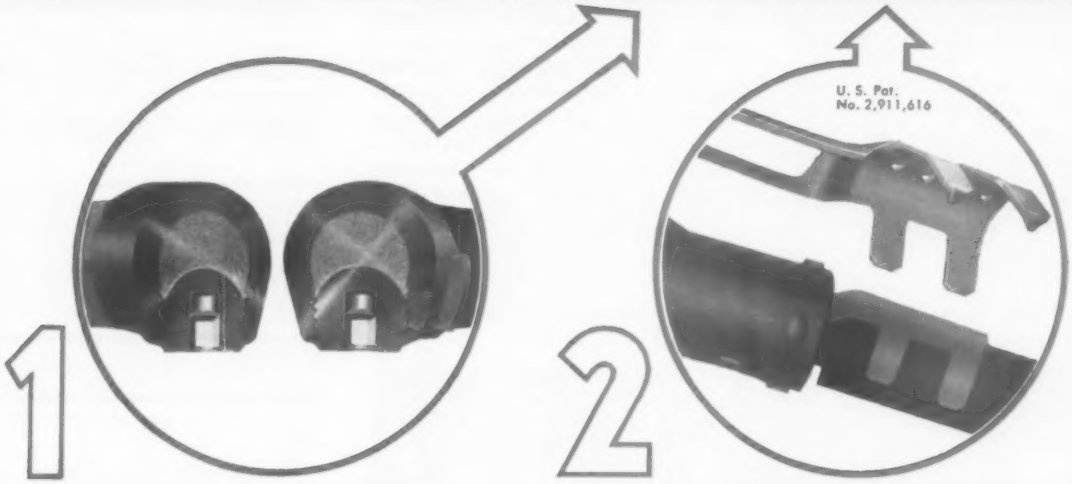

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NEWS of the industry

NEMA and BUSHIPS Produce Electrode Standard

Cooperation between the Navy's Bureau of Ships and the National Electrical Manufacturers Assn. has resulted in publication of a single specification governing the general requirements common to all covered electrodes. This action was reported by J. E. Norcross, Arcos Corp. vice president and chairman of NEMA's subcommittee, at a military-civilian group luncheon held in Washington, D. C., on September 8th.

By using the new standard, MIL-E-22200, government specification writers can cover in 1 or 2 pages what previously required 20 to 30 pages, according to the report. It will now be necessary to specify in detail only the unique properties required of a specific covered welding electrode. This simplification is the result of a 3-year study that revealed an essential uniformity among various specifications regarding the general properties of electrodes, although the authors expressed these requirements in different ways.

Since the Bureau of Ships was given responsibility by the Department of Defense for standardization of welding electrodes, the hope was expressed that writers for all government agencies will make use of the new specification. The full title is Military Specifications Electrodes, Welding, Covered; General Specification, MIL-E-22200 (Ships).

MILITARY-CIVILIAN GROUP AT WASHINGTON, D. C.

Leaders at the NEMA-sponsored luncheon reporting a single specification for covered electrodes. Starting lower left they are: R. T. Brown, Metal and Thermit Corp.; Rear Admiral F. B. Schultz, Bureau of Ships; J. E. Norcross, Arcos Corp.; E. F. Seaman, Bureau of Ships; Capt. E. H. Schantz, Bureau of Ships; J. F. Miller, NEMA's managing director

ASM Dedicates Quarters

On Sept. 14th, the American Society for Metals dedicated its geodesic - domed national headquarters at Metals Park in Geauga County, near Cleveland, with several hundred important leaders from industry, government and scientific circles in attendance.

Highlights of the event were dedication addresses by Clyde Williams and Zay Jeffries, and placement of a time capsule containing nearly a pound uranium metal. Walter Crafts, ASM national president, presided throughout the ceremonies, and presented the building to Allan Ray Putnam, managing

COMING EVENTS

A Calendar of Welding Activity

AWS

Mar. 24–25, 1961. Kansas Welding Show. Kansas National Guard Armory, Wichita.

1961 Annual Meeting & Exposition: April 17–21. Hotel Commodore, New York, N. Y.

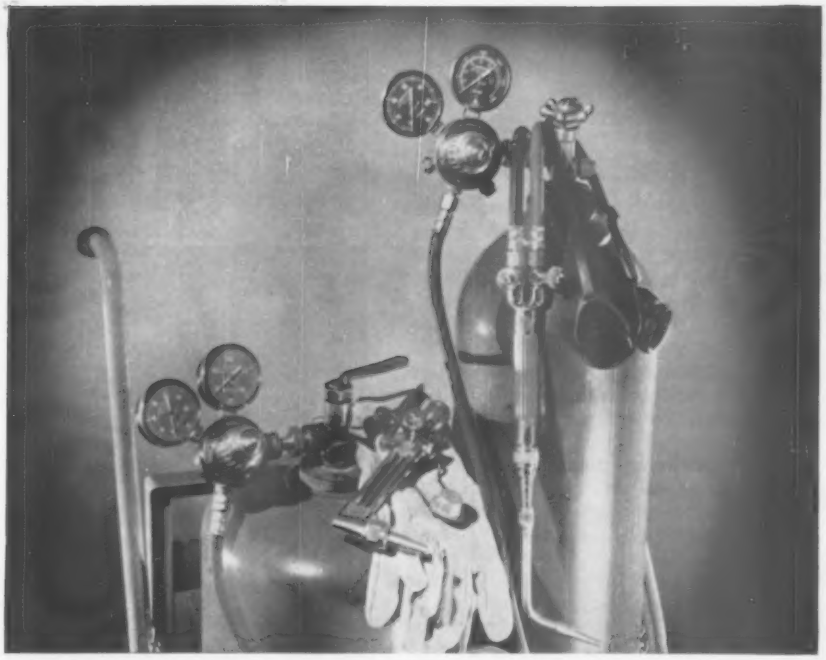
ASM

Mar. 20–24, 1961. 12th Western Metal Congress and Exposition. Pan-Pacific Auditorium, Los Angeles, Calif.

NWSA

November 28, 29, 1960. Southeastern Zone Meeting. Hillsboro Hotel, Tampa, Fla.

December 1, 2. Southwestern Zone Meeting. Hotel Roosevelt, New Orleans, La.



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director, for "increased dissemination of technical information for constantly improving technology in metalworking."

A. O. Smith Research Center

The A. O. Smith Corp. will build an advanced research center at Middleton, Wis., for an estimated $2 million, it has been announced by L. B. Smith, president. Smith said that ground would be broken for the project this fall on an 80-acre tract of land; it is planned to begin advanced research activities in the new facility by the middle of 1961.

Preliminary plans call for the construction of a 50,000 sq ft building of modern design to house the company's advanced research group. Robert McGinn, vice president of research and development for the company, said that research in the new laboratories would be devoted to solid state physics and physical chemistry of materials, as well as the energy processes involved in the utilization of such materials. New product development utilizing the output of this research will also be undertaken.

The advanced research laboratories will begin activities with a staff of approximately 50 scientists and technicians, McGinn said, and ultimately a staff of approximately 100 scientists and highly skilled technical people will be employed on various advanced research projects. Both Smith and McGinn also stressed that being adjacent to the University of Wisconsin will offer an opportunity for advanced educational development for the company's technical staff, provide a close touch with the latest scientific developments, and offer a congenial academic atmosphere which would attract the highest type of scientific personnel needed for advanced research.

It also was pointed out that the Middleton location for A. O. Smith's advanced research laboratories was sufficiently close to the company's other research activities in Milwaukee to permit close liaison and frequent consultation.

ALCOA Gets Foreign Rights

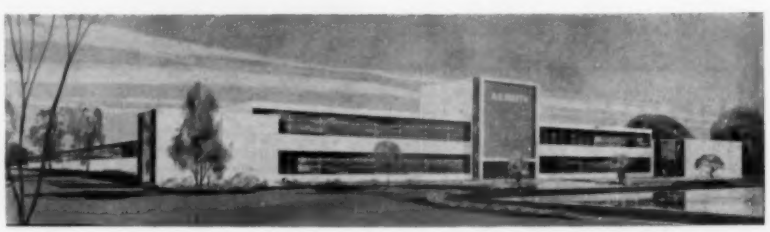
Aluminum Co. of America and Aeroprojects, Inc., West Chester, Pa., recently announced the acquisition by Alcoa of foreign rights to sell, and also license the manufacture of Sonobond ultrasonic metals joining equipment.

Ultrasonic joining tools manufactured by Sonobond Div., a subsidiary of Aeroprojects, Inc., are used to weld, braze and solder metals by the application of ultra-high frequency vibrations. Equipment for these practices is known under the trade names of Sonoweld, Sonobraze and Sonosolder.

Distributors Appointed

Instrument Control Co., 1554 Nicollet Ave., Minneapolis 3, Minn., has appointed the following exclusive distributors for its resistance welding controls and standards products.

Cassimus Co., 651 Folsom St., San Francisco 7, Calif.; Machinery & Welder Corp., 3623 W. National Ave., Milwaukee, Wis.; Stanco Welder & Machinery Co., 9 S. Clinton, Chicago 6, Ill.; Myron Zucker Engineering Co., 708 W. Long Lake Rd., Bloomfield Hills, Mich.; Sem-Torq, Inc., 2115 E. 96th St., Cleveland, Ohio; Resistance Welding Accessories, 17 E. 70th St., New York 21, N. Y.; K. Wm. Ostrom & Co., Inc., 333 Shadeland Ave., Drexel Hill, Pa.; Mills Welding Supply, 110 E. Utica St., Buffalo 9, N. Y.; F-H Welding, Ltd., 92 N. Queen St., Toronto 18, Canada.



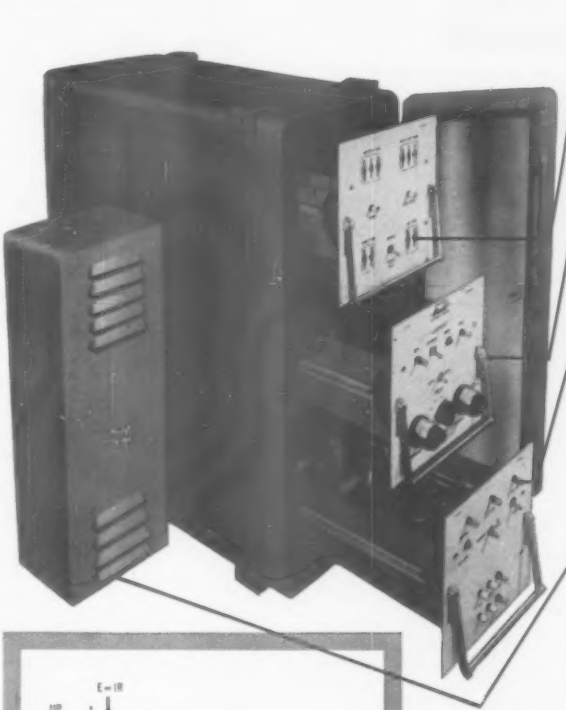
Monautronic V-2 welding control certifies weld quality... cuts rejects and production costs

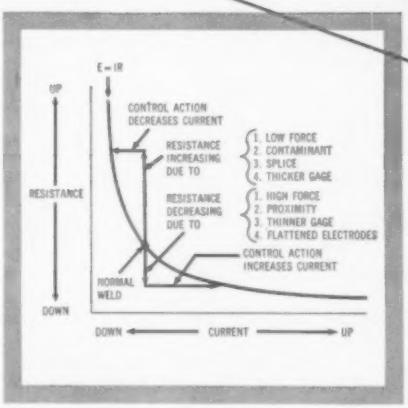
A resistance welding control that automatically compensates for every process variable

The new Monautronic V-2 welding control introduces the concept of feedback control to produce spot-welds of consistently high quality. It makes use of the latest advances in electronic computing to overcome automatically such obstacles to weld quality as line voltage fluctuation, electrode wear, variations in electrode tip force, surface finish and shunting.

The Monautronic V-2 compensates for undesirable variations usually encountered in resistance welding by maintaining voltage across a weld at a constant value. This constraint of voltage amounts to constraint of final weld temperatures, and such temperature control assures production of quality welds.

- **Automatic lockout**—occurs when process variations are so severe that the available current range would not cover the requirements for quality welding. The control detects extreme contamination, failure in the force system, overwelding, poor matching or fitup, and any other conditions that would result in substandard welds.
- **Automatic sequencing**—all provisions for single spot, roll spot or seam welding. Sequencing is 100% accurate, and exceeds NEMA standard specification 3B. Special sequence programming is available.
- **Transistorized design**—for high reliability, compactness, low power consumption.
- **Modular construction**—permits easy removal of the three modules and separate firing unit, simplifies maintenance.
- **Shock and vibration resistant construction**—for long, reliable service in even the most demanding applications.
- **Safety interlock**—for protection of personnel during tip dressing.
- **Tamperproof case**—prevents access to control by unauthorized personnel.


SEQUENCE MODULE—Utilizes digital pulse-type circuitry . . . provides 100% accuracy.
HEAT CONTROL MODULE—Contains automatic and manual heat controls plus lockout devices. Processes input information from weld.
POWER SUPPLY MODULE—Power supply plus required auxiliary safety features.
FIRING MODULE—Provides large currents needed to fire ignitrons. Supplied as separate module.



VOLTAGE CONSTRAINT

Graph shows how voltage control compensates for process variations. Any point on curved line E = IR represents a specific voltage. With normal weld as reference point, certain process variations cause increased resistance, while others cause a decrease. Control action is achieved through change of current to constrain voltage to same level for every weld.

for complete details contact: THE BUDD COMPANY
Electronic Controls Section • Philadelphia 32, Pa.

ELECTRONIC Budd CONTROLS

For details, circle No. 25 on Reader Information Card

now more than ever

radiation monitoring you can bank on

new peace of mind comes to the wearer of this badge. Not only does he always know the full *score* on his personal exposure, but he can confidently rest on its *accuracy*, too. Continuous technical improvement in Gardray film processing and densitometry (direct electronic IBM recording now eliminates all possibility of human error) gives him this positive protection . . .

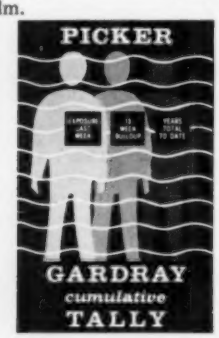
GARDRAY records exposures as low as 1 mr, as high as 300,000 mr.

GARDRAY is sensitive to gamma and x-radiations and beta radiation: reports them separately.

GARDRAY reports are cumulative tallies: (1) current week (2) 13-week total (3) year's total to date.

GARDRAY reports are prompt (two days in and out, average).

GARDRAY identification is doubly-sure: (1) printed on wrapper (2) x-rayed on film.



You can start enjoying this protection (and acquiring this peace of mind) any time. Right now, if you wish, by calling any Picker X-Ray local office. *Or write to*

PICKER
X-RAY CORPORATION
25 So. Broadway, White Plains, N.Y.

For details, circle No. 26 on Reader Information Card

A. O. Smith Office in Washington, D. C.

The A. O. Smith Corp. has opened a Welding Products Division office in Washington, D. C., under the direction of sales representative J. H. Rees.

J. H. Rees

In addition to serving government needs in the nation's capital, Mr. Rees will cover welding customers in Maryland, Virginia and North Carolina. He reports to Philadelphia district manager D. H. Buerkel.

An engineering graduate of Iowa State College, Mr. Rees was A. O. Smith's welding sales representative in Iowa, Nebraska, Kansas and Missouri for six years prior to his new assignment. He also sold in Minnesota and the Dakotas for two years.

Ampco Names Agent

J. K. Bybee will represent Ampco Metal, Inc., as an agent in Southeastern U. S. The appointment, effective immediately, expands Ampco's representation into Georgia, North and South Carolina, Florida and Tennessee. The new agency is located at 3469 Spring Circle, Decatur, Ga.

Mr. Bybee, a former Ampco district manager, has been associated with the Milwaukee firm since 1939.

NCG Provides Scholarships

Two scholarships in welding engineering, to be awarded students at Ohio State University, have been provided by National Cylinder Gas Div., of Chemetron Corp., Chicago, Ill., it was announced by J. L. Adank, president.

Roy B. McCauley, chairman of the department of welding engineering at Ohio State, said "The program . . . will allow us to consider a wider range of prospective students who, without financial help, would not be able to enroll."

Linde Drops Cylinder Line

W. B. Nicholson, president of Linde Co., Division of Union Carbide Corp., announced recently that Linde will discontinue the manufacture and sale of cylinders for propane, refrigerant and anhydrous ammonia service. Machinery for producing these cylinders has been sold to Cylinders, Inc., an affiliate of Newark Steel Drum Co., 1200 W. Blancke St., Linden, N. J., from whom users will be able to purchase the cylinders in the future.

Linde reportedly filled all orders for these cylinders on its books prior to September 30th.

Wilkerson Expands

Ground breaking ceremonies were recently held for a quarter of a million dollar plant facility for Wilkerson Corp., Englewood, Colo., a manufacturer of compressed air products in the Denver area. Harold Sampson, president of the firm, described the new plant as another milestone in Wilkerson's progress from a one-man operation in a small building to an organization employing over 80 people and with international distribution of its products. Sampson said that the 20,000 sq ft building has been so planned that it can be expanded to 60,000 sq ft of floor space at any time.

METALLURGISTS & WELDING ENGINEERS

B.S. thru Ph.D. with experience or interest in welding to perform basic research in arc-welding and welding metallurgy and develop varied new welding processes.

Positions are permanent and offer challenging work, good salaries and opportunities for personal and professional growth. Liberal benefits include well-established pension, group insurance and stock investment plans. Our modern laboratories are located in a pleasant suburban location in north central New Jersey, 45 minutes from New York City.

Mail complete resume with salary requirements to:

PERSONNEL MANAGER
AIR REDUCTION COMPANY, INC.
CENTRAL RESEARCH LABORATORIES
MURRAY HILL, N. J.

For details, circle No. 27 on Reader Information Card →

World's largest single-engine crawler welded with M&T Murex electrodes

The giant Caterpillar D9 tractor is a mountain of earth-moving muscle with a pull of 67,190 lbs. Using its seven-roller tracks, the Cat crawler can claw into the earth, push huge boulders, maul tons of dirt. The average tractor is dwarfed by the size of this monster: 23 feet long and weighing over 75,000 pounds, with equipment. In building its D9 line of crawlers, Caterpillar Tractor Co. used Murex electrodes – products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

PERSONNEL

Langley Appointed Manager

C. J. Langley has been appointed assistant district manager for Air Reduction Sales Co. in Philadelphia, it was announced by A. S. Blodget, Jr., regional sales manager of Airco's eastern region. In his new capacity Mr. Langley will assist N. F. Moody, district manager, in the sale and distribution of all Airco products marketed through the Philadelphia district.

Mr. Langley joined Airco in 1946 and prior to his present appointment was first supervisor of technical sales and then assistant manager-sales in the Boston district from 1953 to 1960.

Mr. Langley has been a member of the AMERICAN WELDING SOCIETY for the past 16 years and is affiliated with the Lehigh, Philadelphia and Boston chapters.

Tweco Advances Five

R. L. Townsend, president, Tweco Products, Inc., Wichita, Kan., has announced several advancements. J. T. Phillips has been promoted from production manager to general sales manager. L. J. Hendrich from Harper, Kan., branch plant manager to general production manager. J. L. Townsend AWS company secretary, has taken over the duties of advertising and sales promotion manager. Jack R. Kester assumes his new duties as new product and tooling development engineer. Wm. R. Roberts is the new manager at the Harper Branch Plant.

C. J. Langley

Square D Names General Sales Manager

The appointment of Ray W. Thompson to the position of general sales manager, Marketing Division, has been announced by M. P. Kartalia, vice president, marketing of Square D Co. In his new capacity Mr. Thompson will operate from the company's new corporate headquarters in Park Ridge, Ill. Mr. Thompson joined Square D as a student engineer in 1931, and has since been promoted several times. He has been serving as midwestern region manager during the past year.

Concurrent with Mr. Thompson's appointment, Kurt Morris has been named midwestern region manager. Formerly merchandise sales manager in charge of Square D regional warehouses, Mr. Morris will make his headquarters in the offices of the Schiller Park, Illinois plant. William J. Moriarity will assume Mr. Morris' warehouse responsibilities while continuing in his present position as manager, distributor relations.

Holder Named Manager

M. S. Holder has been named regional manager, in Indiana and Southern Illinois, by Eutectic Welding Alloys Corp., Flushing, N. Y. He was previously a field supervisor in the area. Mr. Holder joined Eutectic as a technical representative in 1954, and was named a supervisor in 1956.

J. L. Townsend

McGahey Made Representative

Appointment of W. McGahey, Jr., as representative for processing and fabrication services has been announced by the Wallco and Stainless Processing Div. of Wall Colmonoy Corp.

In his new association, McGahey will serve customers in the state of Indiana in sales of tubular and brazed assemblies and heat treating and bright annealing services for Wallco Div. and in sales of hydrogen and vacuum furnace processing work for Stainless Processing Div. Offices will be at 1605 Curdes Ave., Fort Wayne, Ind.

Taylor Becomes Manager

The A. O. Smith Corp. has announced the promotion of T. L. Taylor to group merchandising manager in its Milwaukee, Wis., central marketing staff. Mr. Taylor's initial duties will include responsibility for the programs of the firm's Welding Products Div. and Electric Motor Div.

Prior to assuming his new duties, Taylor sold A. O. Smith welding equipment for eight years in the field. In that period, he was headquartered in Milwaukee, Lancaster, Pa., and, most recently, Cleveland, Ohio.

Ryle Made X-ray Manager

D. Ryle AWS has been appointed manager of the newly formed X-ray Div. of Labquip, Inc., midwestern distributor for the Balteau Electric Corp. As divisional manager, Mr. Ryle will be responsible for sales and service in the Illinois, Michigan, Wisconsin and Indiana territory. He brings 15 years of X-ray experience to his position.

Menzel Appointed

Frederick P. Menzel has been named manager of a newly created engineering sales department at the United Welding Co., Middletown, Ohio, a subsidiary of Aeronca Manufacturing Corp.

According to L. T. Kenney, vice president and general manager, Menzel was transferred from Aeronca Manufacturing Corp. to supervise the welding firm's efforts to provide quality weldments and additional engineering services for its customers.

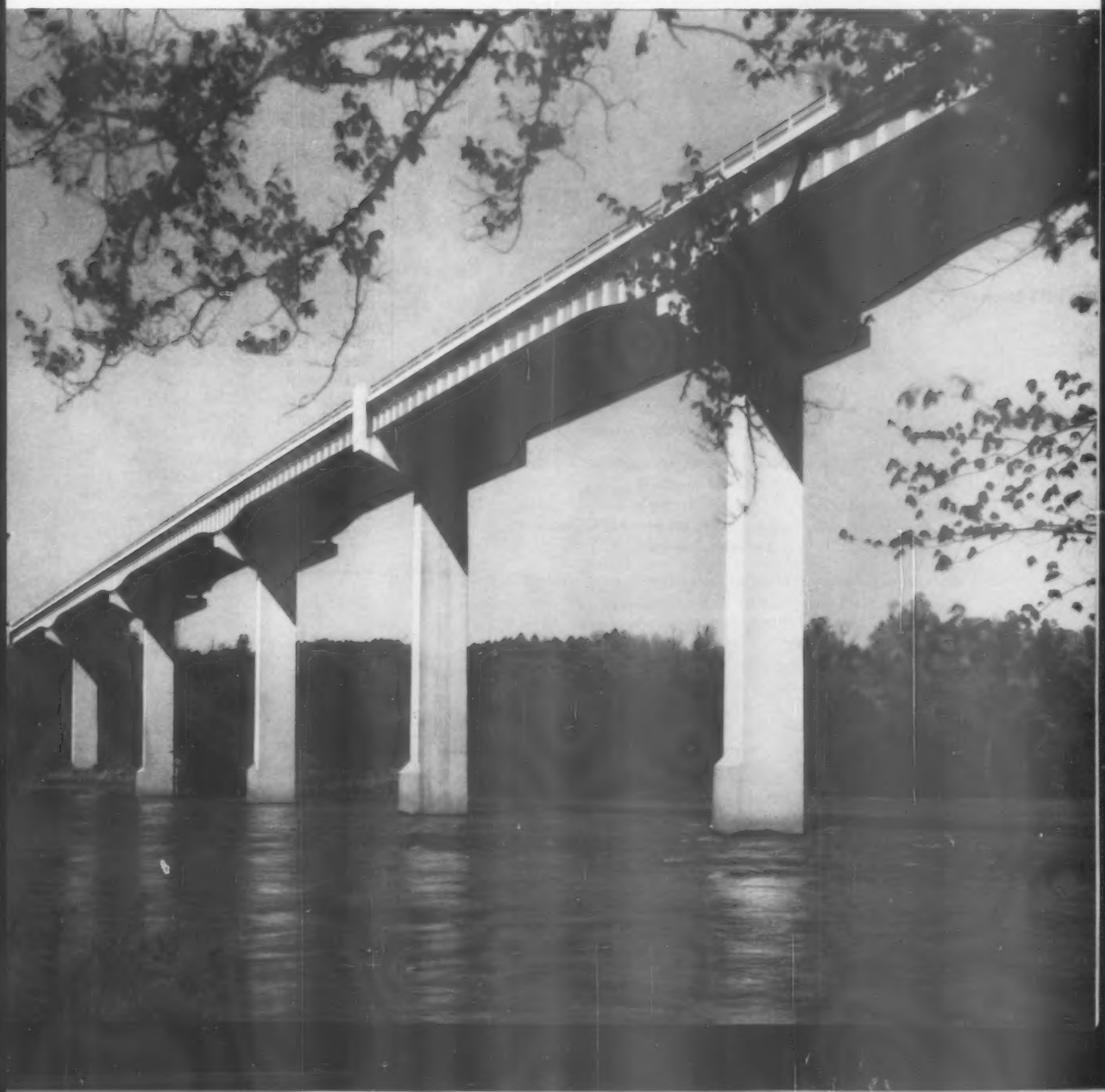
Menzel joined Aeronca in December 1957, as chief of manufacturing engineering. He studied mechanical engineering at John Hopkins University, Baltimore, Md., and is now a professional engineer.

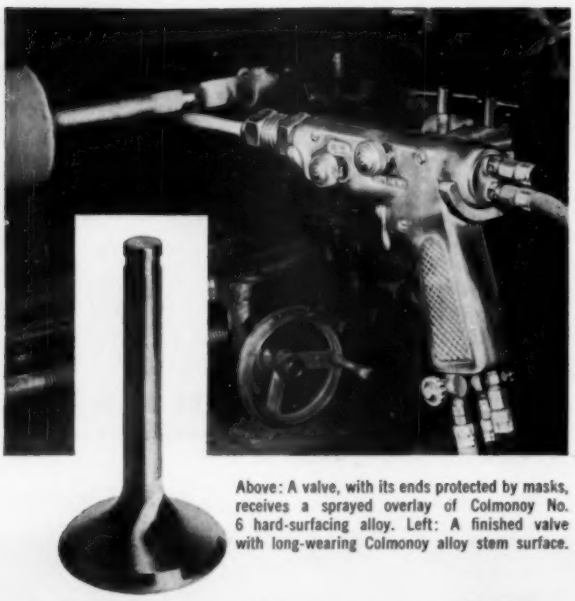
For details, circle No. 28 on Reader Information Card →

Nation's top-award-winning bridge welded with M&T Murex electrodes

Some time ago, the American Institute of Steel Construction announced its awards for the most beautiful bridges opened during 1958. There were over 100 entries in four classifications. Top award in its class went to the Louie Morris Memorial bridge in Hartwell, Ga. This was the sole first award to go to a welded bridge. On this winner, all welding was done by Calvert Iron Works with M&T Murex electrodes – products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING





Above: A valve, with its ends protected by masks, receives a sprayed overlay of Colmonoy No. 6 hard-surfacing alloy. Left: A finished valve with long-wearing Colmonoy alloy stem surface.

Colmonoy Spraywelder Builds Longer Life into Aircraft Valve

To overcome corrosive pitting and abrasion of aircraft engine valve stems, more than one manufacturer has chosen Colmonoy No. 6 alloy to provide a long wearing stem surface. Colmonoy No. 6 stops the pitting and excessive wear which necessitates frequent engine overhauls. The Colmonoy Spraywelder is used to apply the powdered alloy. It works fast and makes smooth, controlled-depth overlays that finish up in minimum time.

Besides being an ideal method of applying a hard surface to finished machined parts, the Spraywelder employs the finest of hard-surfacing materials: Colmonoy nickel-base alloys. There are now five Colmonoy alloys available as Sprayweld* Powders.

Call a Colmonoy sales engineer to get an appraisal of your wear problems and information on just how Colmonoy alloys and methods might solve them. Colmonoy alloys (nickel-, cobalt-, and iron-base) are also applied in many other ways: as welding rod, electrodes, paste, and as castings. Learn more about this remarkable group of alloys.

Ask for the Spraywelder Catalog and Colmonoy Hard-Surfacing Manual No. 79.

*Registered trade-mark

HARD-SURFACING & BRAZING ALLOYS

WALL COLMONOY CORPORATION
19345 JOHN R STREET • DETROIT 3, MICHIGAN

Buffalo • Chicago • Houston • Los Angeles • Morrisville • New York • Pittsburgh • Montreal • London, England

For details, circle No. 29 on Reader Information Card

Fassinger is Sales Engineer

Scott-Tarbell, Inc., of Cleveland, Ohio, announce the appointment of C. R. Fassinger as sales engineer. Mr. Fassinger is a member of the AMERICAN WELDING SOCIETY, Cleveland Section, and has been connected with the welding industry for 12 years as plant manager, service engineer and chief engineer.

Jones Named Group Executive

J. F. Jones has been named group executive in charge of the A. O. Smith Corp.'s Industrial Products Group, it was announced recently.

Prior to his new appointment, Mr. Jones was general manager of A. O. Smith's Automotive and Railway Products Group. The Industrial Products Group includes electric motors, welding products, reinforced plastics and the Crowley division. He succeeds J. Randall, vice president, who has resigned to accept another position.

McVickar Appointed Manager

E. S. J. McVickar was appointed manager of Mining and Welding Cable Sales, National Electric Div., H. K. Porter Co., Inc. For the past ten years Mr. McVickar was associated with General Cable Corp., most recently as product sales manager for special cable marketed in the mining and welding industries. In his new position he will be responsible for expanding National Electric's sales of cables to these industries.

For the past five years he has participated in the activities of the American Mining Congress, National Welding Supply Association, Open Pit Mining Association, Illinois Mining Institute, Kentucky Mining Institute and New Mexico Mining Association.

OBITUARY

Samuel Shaykin

Samuel Shaykin, president and founder of Chicago Welding Sales Co. and its subsidiary York Engineering Co. passed away on Sept. 6, 1960, at the age of 72.

He was considered a pioneer in the welding industry, having started with the Searchlight Acetylene Co. in 1910, which was later absorbed by Air Reduction Sales Co. After 20 years with Airco, he formed Chicago Welding Sales Co. in 1931 and York Engineering Co. in 1935.

For details, circle No. 30 on Reader Information Card →

World's toughest "lawnmower" welded with M&T Murex electrodes

Thicket, field, forest—all would be duck soup for this 16-ton husky. The first of its kind to be self-propelled, the Marden brush cutter can clear a seven-foot swath through dense undergrowth with trees up to 6" in diameter. And as it clears, it forces the vegetation into the ground to act as humus. In building its rugged brush cutters, the Marden Manufacturing Company uses M&T Murex dependable electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

New Literature

Manifolds and Regulators

"Oxweld" industrial gas regulators and portable manifolds are described in a 16-page catalog available from Linde Co., 270 Park Ave., New York 17, N. Y. Included are complete specifications and ordering information for regulators that are available for use with all industrial gases and completely portable manifolds for use with oxygen and acetylene. Inlet and outlet connections are listed according to the American Standards of the Compressed Gas Association. Recommended uses and installations are included in the description of each regulator.

In addition to covering single- and two-stage regulators for station and manifold service, the catalog also describes a new line of single-stage regulators *without gages* and regulator manifolds for use in late model premix beverage dispensing machines. Gageless regulators are said to represent an important advance in regulator design completely eliminating the costly and annoying problem of gage replacement.

For your free copy, circle No. 51 on Reader Information Card.

Carbon Dioxide for Welding

An 8-page brochure on the uses of carbon dioxide in the welding industry has just been issued by the Pure Carbonic Co., 150 E. 42nd St., Div. of Air Reduction Co., Inc., New York 17, N. Y. It describes the characteristics of CO_2 gas-shielded metal-arc welding of mild steel and low-alloy steel, the advantages of CO_2 in welding, and the various welding processes employing carbon dioxide as a shielding gas. Illustrations are included for some of the many applications using carbon dioxide welding today.

For your free copy, circle No. 52 on Reader Information Card.

Electrode Data

A 20-page illustrated booklet giving complete information on arc-welding electrodes, including specifications, chemical requirements and methods of estimating electrode consumption, is available from National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill. The booklet is said to explain and list AWS and ASTM specifications for mild, low-alloy, and stainless-steel electrodes; chemical requirements for all weld metal are given; and welding characteristics of mild-steel electrodes are listed.

The booklet (NH-504) is described as outlining eight points to consider in choosing the correct mild-steel electrode, and listing NEMA standard identification markings for electrodes. The booklet is also described as containing standard welding symbols; a chart to show how qualities of welds are affected by welding speed, arc length, and current; and four pages of charts to help the welder estimate electrode consumption for manual or automatic arc welding.

For your free copy, circle No. 53 on Reader Information Card.

Electrode Selector

A pocket slide chart that provides finger-tip accessibility of pertinent resistance welding data is available from Ampco Metal, Inc., 1745 S. 38th St., Milwaukee, Wis. The chart is $9^1/_4$ x 4 in. and is stated to make it possible to select the proper electrodes for joining many commonly-welded ferrous and nonferrous alloys; top and bottom electrodes are indicated for more than 160 alloy combinations. The chart is also said to include data for determining the proper spot-welding and seam-welding schedules for various thicknesses of low carbon steel with a conversion table for other alloys.

For your free copy, circle No. 54 on Reader Information Card.

Alloy Welding Manual

A 56-page catalog and instruction manual on welding, brazing, soldering alloys and fluxes is available from the All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y. A 4- x 7-in. pocket-size manual is also offered in Spanish on written request.

Physical properties, major uses, detailed application instructions and techniques for welding, brazing, soldering, cutting and hard facing are included for All-State's line of products for joining all commercial metals. Charts and tables are also included while products are indexed by major metal use. Shortcuts, hints, chemical composition and data on automatic and semi-automatic welding wire are likewise given.

For your free copy, circle No. 55 on Reader Information Card.

Resistance-welding Tables

The Taylor Winfield Corp., 1048 Mahoning Ave., Warren, Ohio, has issued an 8-page brochure with tables which simplify calculation of the electrical power supply required by resistance welders. Electrical-demand and duty-cycle factors are tabulated to establish minimum transformer kva ratings. These tables are said to establish the maximum electrical duty cycle of a transformer under various demand loads.

For your free copy, circle No. 56 on Reader Information Card.

Automatic Fusion Welding

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., has issued "A Pictorial Report of Sciaky Developments in Highly Precise, Fully Automatic Fusion Welding Equipment." Features within this 27-page report are actual applications where subject equipment has been in use for the past two years in North American Aviation's B-70 program, Raytheon's "Hawk" processing, as well as others. Equipment descriptions are also contained.

For your free copy, circle No. 57 on Reader Information Card.

Mash Seam Welding

Advantages of mash seam welding as a high-speed, high-strength, low buildup method of coil joining are described in a catalog released by National Electric Welding Machines Co., 1846 Trumbull St., Bay City, Mich.

The 6-page publication describes engineering specifications and work ranges of 11 types of special and standard automatic coil joining welders, including mash seam, spot, arc and lap seam equipment.

It also contains information on automated units performing shearing, welding and cold rolling operations.

For your free copy, circle No. 58 on Reader Information Card.

Welding Studs

Shielded Stud Welding Co., 2043 Gaylord St., Long Beach 13, Calif., has issued a six-page pamphlet showing specifications of their welding studs. Among the many described are threaded studs, collar studs and insulation studs.

For your free copy, circle No. 59 on Reader Information Card.

Maintenance Wear Tests

"Facts About Metal Wear For Maintenance Men" is the title of the recent data sheets made available by the Rankin Manufacturing Co., 616 S. Marengo, Alhambra, Calif. Subjects include measuring wear resistance, making your own tests and effect of hardness.

For your free copy, circle No. 60 on Reader Information Card.

Corrosion Data Charts

The corrosive effects of almost 400 different materials on 16 types of metals appear in corrosion data charts recently published as Technical Service Bulletin No. 101 by the Nooter Corp., 1400 S. Third St,. St. Louis 66, Mo. The charts indicate the corrosion resistance of the metals to various concentrations of more than 250 chemical salts and acids, as well as more than 100 common materials such as water, glue, fruit juices, milk, meats, salt, turpentine and many others.

For your free copy, circle No. 61 on Reader Information Card.

Spot Welding Hardenable Steels

The Taylor-Winfield Corp., 1048 Mahoning Ave., Warren, Ohio, has an 8-page brochure describing equipment and procedures recommended for spot welding hardenable steels. Weld quality is classified and data charts summarize the welding schedules used on various steels. A number of steels to which spot welding technique can be adapted are listed. Step by step instructions are included for setup, welding and testing.

For your free copy, circle No. 62 on Reader Information Card.

Welding Electrode Chart

A new 23 x 35-in. electrode wall chart giving description, number, color code, mechanical properties, size, current range, procedure and application information on the complete line of Hobart arc-welding electrodes is available from Hobart Brothers Co., Troy, Ohio. Other valuable welding information covers welding symbols, welding arc, causes and cures of common welding troubles, typical deposition rates and a metal hardness conversion table.

For your free copy, circle No. 63 on Reader Information Card.

Work-glove Guide

The Glove Division of the Riegel Textile Corp., Conover, N. C., offers a selector manual covering basic types and styles of work gloves to buyers, safety engineers and purchasing agents. According to the manufactuer, the guide is for quick reference and is complete with information on basic cuts, cuff styles and other specification detail. The guide is said to contain tips on points such as grades of leather, chemical resistance and physical properties of various plastic coatings; basic features of other materials are also covered. A second section is slated to contain on-the-job case histories where changes in work glove specifications increased hand protection and lowered glove costs. A company spokesman states that "We believe this manual will be invaluable to anyone concerned with accident prevention or glove purchasing."

For your free copy, circle No. 64 on Reader Information Card.

BATEMAN
BANTAM
IRON WORKER

THE ONLY IRON WORKER OF ITS KIND ON THE MARKET TODAY

No Grinding Necessary After Cut. One Stroke Cycle Clutch Operated by Hand or Foot.

The Bateman "Bantam" cuts 2" x 2" x ¼" angles and ¼" x 4" flats. Standard punches will fit this machine. The Coper will cope 1¼" through ⅛" material. It will punch ½" hole through ¼" material. With the clutch open, the Bantam will make 44 strokes per minute. It is made of high-grade cast iron, with the clutch, pin and dog made of hardened steel. The blades are made with tool steel. It is powered with a fly wheel and gear drive, and uses a small ¾ hp motor, 1750 rpm.

Bateman Bantam with punch....$575.00
Shear only $495.00
Shipping wt. 750 lbs.

BATEMAN FOUNDRY & MACHINE
MINERAL WELLS, TEXAS

For details, circle No. 31 on Reader Information Card

Colossal Crawler

Beautiful bridge

Mammoth "mower"

A tractor that shoves huge rocks and mounds of earth . . . a bridge that wins an award for beauty . . . a brush-cutting machine that clears dense undergrowth . . . all must be both carefully engineered and strongly built to do their jobs properly. It's significant that all were welded with M&T Murex electrodes.

On one important job after another, Murex electrodes have met the most demanding specifications. With more than 1000 types and sizes to choose from, you're almost *sure* to find a Murex electrode that exactly meets your requirements. Send for "electrode selector" booklet.

M&T MUREX welding products

METAL & THERMIT CORPORATION
General Offices: Rahway, New Jersey

For details, circle No. 32 on Reader Information Card

New Products

Push-type Welding Gun

A new air-cooled push-type model AH60-B welding gun and model AHF-O wire feeder for use with Aircomatic gas-shielded metal-arc welding are now available from Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. The gun has a goose-neck nozzle assembly for welding in hard-to-reach places, and a lever type trigger for ease of operation. It can be used with buried arc and spray arc welding using CO_2 as a shielding gas or with argon in standard gas-shielded metal-arc welding.

The wire feeder includes a remote speed control with 15 ft of service cord to provide wire-feed speed adjustment, up to 600 ipm, near the work. Operating on 115 v, 60 cycle ac, the feeder can be used with either Constant Arc Voltage or Fillerarc motor generator power sources.

For details, circle No. 101 on Reader Information Card.

E6011 Electrode

Hobart Brothers Co., Troy, Ohio, has developed a new E6011 electrode identified as Hobart 335A. It has a small amount of iron powder in the coating to improve arc stability, to decrease spatter, and to increase deposition; it reportedly can be used on ac or dc, straight or reverse polarity.

Available in $^3/_{32}$ in. diam in 12 in. lengths; $^1/_8$, $^5/_{32}$, $^3/_{16}$, $^7/_{32}$ in. in 14 in. lengths and $^1/_4$ in. in 18 in. lengths. Standard package is 50 lb for $^1/_8$ in. and larger, 25 lb for $^3/_{32}$ in.

For details, circle No. 102 on Reader Information Card.

Jumbo Ignitron

A new "Jumbo C" size ignitron as announced by General Electric Power Tube Department, Schenectady 5, N. Y., is said to permit a 50% boost in power output of standard size C welders without increasing equipment dimensions.

The electrical capabilities of the new tube, type GL-7681, are midway between those of the size C (GL-5552A) and size D (GL-5553B) welding ignitrons. While the Jumbo C tube is slightly longer than the size C, its diameter is the same.

In a-c control service, two of the new tubes in inverse parallel control 1800 kva with a corresponding anode current of 113.5 amp. With a maximum anode current of 210 amp, the corresponding maximum demand is 600 kva. The GL-7681 is rated at 600 v rms for these capabilities.

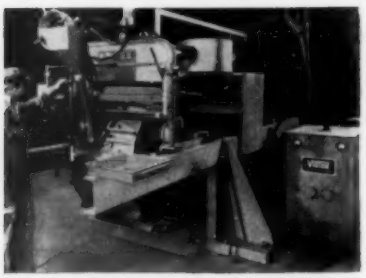
The GL-7681 may be used in frequency changer welding, where six tubes can control 2250 amp peak at 1200 inverse. The corresponding average current for peak ampere voltage conditions is 30 amp.

For details, circle No. 103 on Reader Information Card.

Grouser Bar Welding Machine

An automatic rebuilder, said to cut in half the time required for renewing tractor grouser pads, has been announced by Victor Equipment Co., 844 Folsom St., San Francisco 7, Calif.

Called the Victor grouser bar welding machine, this machine is self-loading and reportedly handles all lengths and widths of track without disassembly. An oxyacetylene torch automatically trims the grouser bar to be reconditioned. Then an air-hydraulic fixture places new bar in curved position for welding. There is said to be no need for tacking and no grouserpad bowing after welding. Victor continous-coil wires is used for welding.



For details, circle No. 104 on Reader Information Card.

Metering Regulators

The Harris Calorific Co., 5501 Cass Ave., Cleveland, Ohio, has announced a complete line of metering regulators for oxygen, carbon dioxide, helium, nitrogen, hydrogen, propane, acetylene and argon. These regulators are said to be extremely accurate and can be mounted in any position without affecting the accuracy of flow; the gage dial is designed to show actual flow in cubic feet per hour consumed.

For details, circle No. 105 on Reader Information Card.

Drum Welding Machine

A new automatic drum welder reported capable of producing containers ranging from the standard 100-lb drum to 55-gal barrels for the food, chemical and petroleum industries, has been developed by National Electric Welding Machines Co., 1846 Trumbull, Bay City, Mich.

The machine is described as a basic mash seam welder equipped with a number of auxiliary functions including an automatic roll

For details, circle No. 33 on Reader Information Card

Material Evidence — NOBODY PUTS AS MUCH INTO A WELDING MACHINE AS A. O. SMITH

To prove our case — that only A. O. Smith still makes an Extra-Heavy-Duty welding machine—we've put our evidence on the table. We submit that, while other machines have been "trimmed down" to sell for less, A. O. Smith Extra-Heavy-Duty welders have all the "guts" the old-timers had. That there has been no stinting on copper, iron or power. That there has been no attempt to cut corners on materials and components—no compromise with value to meet a price.

Examine the evidence! Then make your own value analysis. We are sure that the verdict will be in favor of A. O. Smith — that it's sound judgement to pay a little more for much more machine. Analyze the value when you consider the price. It's value that pays off in longer life and superior performance.

EXHIBIT A — COILS A. O. Smith's extra-heavy copper secondary (at left) and primary (at right) coils are the heaviest in the field — together weigh 185 lbs. Note how competitive coils skimp on material. Here's heavy-duty value that adds up to longer production life . . . a machine that operates on a temperature rise of only 55°C — lowest of any machine on the market.

EXHIBIT B — CAPACITORS Standard with A. O. Smith Extra-Heavy-Duty welders is the industry's maximum power factor correction — 134 M.F.D. total. This high power factor means that the current taken from the primary line is lower than with any other machine when comparable ratings are matched — value that means money in your pocket through lower power bills.

EXHIBIT C — MOTOR Power behind the A. O. Smith extra-heavy-duty cooling system is big, totally enclosed lifetime-lubricated motor. Note "junior-size" motors used by competitive welders. Only A. O. Smith's heavy-duty motor supplies dependable starting torque . . . provides more air for cooler operation and longer machine life.

EXHIBIT D — FAN Biggest fan in the field. Air is circulated by an 18-inch industrial-type fan blade as compared to fans much smaller on other welding machines. And A. O. Smith's blade is dynamically balanced, scientifically pitched to deliver maximum ventilation down through the coils. Blast guides direct full force of the fan right on target.

For details, circle No. 33 on Reader Information Card

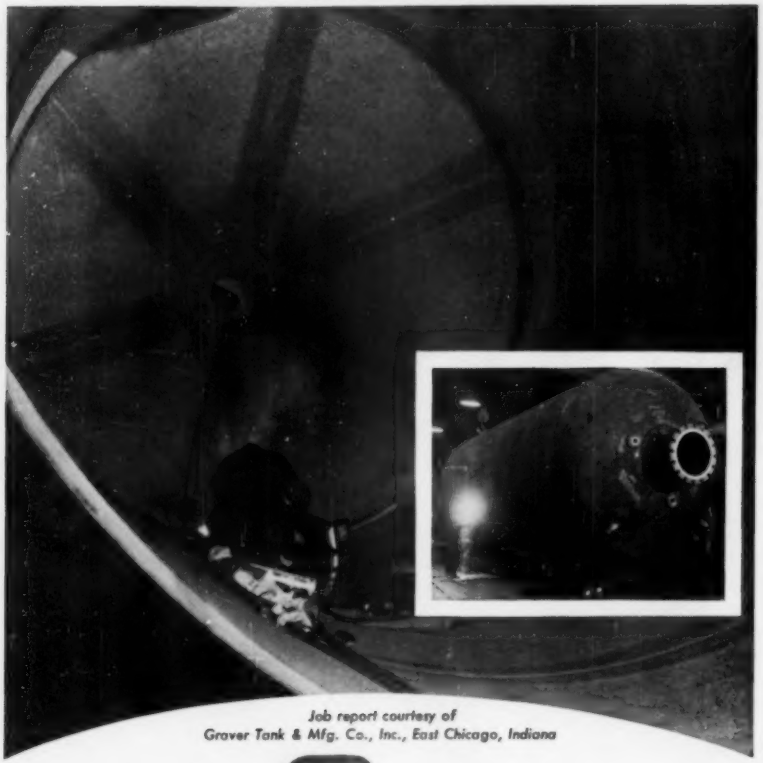
COURT CALENDAR

Case for value analysis — A. O. SMITH EXTRA-HEAVY-DUTY welding machine versus the field. Exhibits shown in front row on table are principal components used in the standard A. O. Smith EXTRA-HEAVY-DUTY welding machine. Comparable components used in other well known brand welding machines are displayed in rear rows.

Through research ... a better way
A.O.Smith
CORPORATION
WELDING PRODUCTS DIVISION
Milwaukee 1, Wisconsin
A.O.Smith INTERNATIONAL S.A., Milwaukee 1, Wis., U.S.A.

For details, circle No. 33 on Reader Information Card

When stainless welds must be free of microcracks



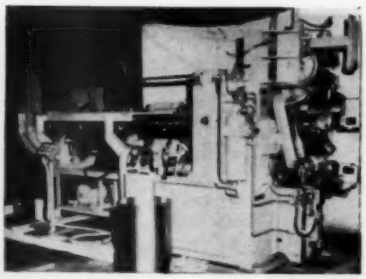
Job report courtesy of
Grover Tank & Mfg. Co., Inc., East Chicago, Indiana

WELD WITH ARCOS

STAINLESS ELECTRODES

This 93,400-lb. 3500 cu. ft. digester is installed at Finch, Pruyn and Company, Inc., manufacturers of printing and converting papers. It converts hardwood into paper pulp using highly corrosive acids at high temperatures, and pressures of 200 psig. The digester is made of Type 316 ELC 20% stainless clad on ASTM A-212 Grade B firebox steel. To assure sound, long-life corrosion-resistant welds, three grades of Arcos CHROMEND Electrodes were used. All welding was manual. The resultant welds were completely free of micro fissures or cracks—more proof why Arcos weld metal is used so widely to combat destructive and costly corrosion. Write for an Arcos Stainless Application Chart. ARCOS CORPORATION, 1500 South 50th Street, Phila. 43, Pa.

For details, circle No. 34 on Reader Information Card



former. The unit is basically a scaled-down version of the company's 700-unit-per-hr drum welder and is said to be designed to meet plant hourly production requirements of 350 fifty-five gallon barrels or 500 one-hundred pound drums.

The 250-kva transformer-powered unit reportedly seams stock ranging from 18 to 26 gage thick on sheets from 40 to 20 in. long; quick-change hour-glass rolls mounted in an "A" frame provide the diameters within the machine's working range. In operation, precut sheets are manually fed into the roll former. A foot pedal activates a sequenced transfer mechanism which carries the work to the weld station.

For details, circle No. 106 on Reader Information card.

Tungsten-arc Welding Machine

A new balanced wave, transformer type power source for use with tungsten-arc-welding equipment was recently placed on the market by Air Reduction Sales Co. 150 E. 42nd St., New York 17, N. Y. Designated the Airco C-Bee (capacitor balanced) Balanced Wave Heliwelder, it is said to be exceptionally good for welding aluminum and magnesium using alternating current. It can be used with both manual and semiautomatic or automatic Heliweld equipment.

Features are reported to include capacitor balancing; high open circuit voltages (165 v) for maximum arc stability; five broad overlapping ranges for applications requiring 20 to 400 amp; good wave form in all ranges; electric control of amperage output for remote control with standard accessories; and power factor correction.

The machine is stated to be rated at 300 amp, 100% duty cycle; it is available in two models: for manual applications with gas and water controls and high frequency unit built in; for semiautomatic and automatic operation with gas and water controls, but without the high frequency unit which is available separately.

For details, circle No. 107 on Reader Information Card.

Natural-gas Brazing Torch

The Harris Calorific Co., 5501 Cass Ave., Cleveland, Ohio, announces its No. 19-S Torch with the 1390 "H" tip for use with natural gas where brazing or silver soldering is necessary. This torch will reportedly operate on high, medium or low pressures and is said to produce an extremely hot but clean flame.

For details, circle No. 108 on Reader Information Card.

Safety Glasses

American Industrial Safety Equipment Co., 3500 Lakeside Ave., Cleveland 14, Ohio, has added two new models to the Eye Gard "Adapta-Spec" line of safety spectacles. No. 471 "Adapta-Spec" features clear safety lens, spatula temples and reportedly partial side shield; the No. 479 has green safety lens, cable temples and perforated side shields. Made of durable butyrate plastic, the unique "Adapta-Spec" frame and bridge are said to fit the facial contour of more than 95% of wearers.

For details, circle No. 109 on Reader Information Card.

Hard-facing Electrode

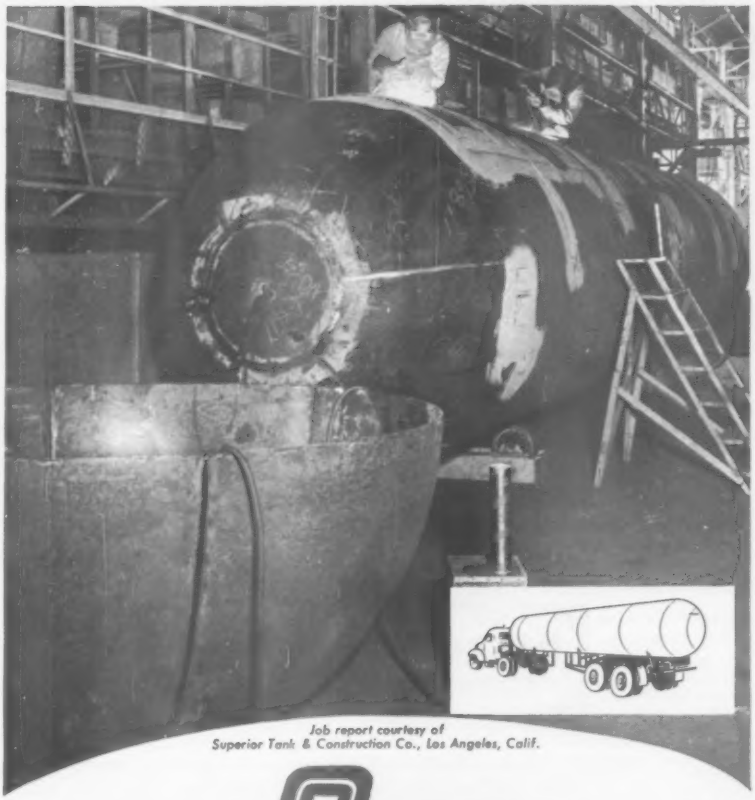
The Stoody Co. Whittier, Calif., has announced the availability of a new electrode—Stoody 1105—for reclaiming such equipment as large sprockets, churn drills, drive tumblers, tractor grousers and most wearing parts subject to severe impact and abrasion.

Stoody 1105 is manufactured by extruding an iron powder coating containing chromium, manganese, molybdenum and vanadium on a mild steel core wire. Welding with ac or dc is said to have smooth arc action, low spatter and a readily removed slag covering. The rod is applied as stringer beads, in weaving passes, or it may be dragged. The deposition rate is high, with a reported efficiency of 70%. The electrode can be applied to carbon and low alloy steels but is not suitable for welding on manganese steel or cast iron.

Rockwell C hardness ranges from 36 to 42, depending on current and polarity. This material will work-harden only 2 to 4 points. The electrode is produced in $^{5}/_{32}$ and $^{3}/_{16}$ in. diam, 14 in. length, and in $^{1}/_{4}$ in. diam, 18 in. length. It is packaged in 50-lb cartons.

For details circle No. 110 on Reader Information Card.

How X-Ray Quality Welds Make Low Alloy Steels Pay Off



Job report courtesy of Superior Tank & Construction Co., Los Angeles, Calif.

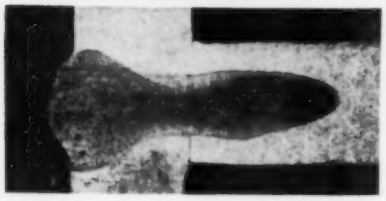
WELD WITH ARCOS

LOW HYDROGEN ELECTRODES

The vessel being welded is part of an L.P.G. tank truck. For high strength with low weight—USS "T-1" steel is used and welded with Arcos Ductilend 110 Electrodes. These tanks meet or exceed ASME code requirements . . . and all Ductilend 110 welds qualify with X-ray soundness. Ductilend 110 is an Arcos Low Hydrogen Electrode especially developed for welding high strength notch tough steels of the 110,000 psi tensile strength range. Data sheet on request. ARCOS CORPORATION • 1500 South 50th Street, Philadelphia 43, Pa.

For details, circle No. 35 on Reader Information Card

Who said: "Un-weldable?"



Before you call it "un-weldable" check it out on the NRC Electron Beam Welder. Problems posed by reactive metals, dissimilar materials, heat sensitivity, and unusual geometry are being solved daily.

•Tungsten, tantalum, columbium, zirconium, etc. are welded free of contamination and porosity • Finish machined parts are joined without distortion • Sensitive instruments are evacuated and sealed • Precision welds are made at the bottom of a 1/16" slot or between two surfaces meeting at an acute angle • Depth/width ratios greater than 4/1 are attained.

Try NRC E/B Welding . . . a special Small Lot Welding Service is available at hourly rates, or you can get a complete E/B installation for less than $16,000! Call or write now.

A Subsidiary of National Research Corporation

Dept. J-11
160 Charlemont St.,
Newton 61, Massachusetts
DEcatur 2-5800

NRC EQUIPMENT CORPORATION

For details, circle No. 36 on Reader Information Card

Thyratrons for Pulse-power Welding Machines

Two high-voltage gas-mercury thyratrons, designed for ignitor firing in pulse power welders, have been announced by General Electric Power Tube Department, Schenectady 5, N. Y. Identified as GL-7725 and GL-7726, the tubes are said to have maximum peak anode voltage ratings (inverse and forward) of 3500 v. They were specifically designed for use with General Electric coaxial welding ignitrons but can be employed in other high-voltage service as well.

Electrically, the tubes are identical. Each reportedly operates at maximum cathode peak current of 30 amp; maximum cathode average current of 2.5 amp with a maximum averaging time of 5 sec.

Mechanically, the tubes differ in that the GL-7726 has a large lug-type base while the GL-7725 employs the conventional plug-in base. Except for higher voltage ratings, the GL-7725 is identical in size, configuration and other ratings to the GL-6011/710; the GL-7726 is likewise identical to the GL-7518.

For details, circle No. 111 on Reader Information Card.

Line Station Valve with Integral Check

A new combination shut-off and check valve for use with oxygen and fuel gas at station outlets of line distribution systems has recently been announced by The Bastian-Blessing Co., 4201 W. Peterson Ave., Chicago 46, Ill. The integral back check valve is said to assure flow in only one direction and effectively stop possible flashback or backfire. The back check feature reportedly eliminates the need for a separately installed check valve.

Designed for working pressures to 400 psi, RegO model 7160 and 7161 line station valves have rugged forged brass bodies, brass trim, and resilient seat and diaphragm. Outlet forms comply with International Acetylene Association recommended standards. Other outlet forms are available within forging limits. An outlet cap and chain assembly is furnished.

For details, circle No. 112 on Reader Information Card.

Mobile Welding Machine

Hobart Brothers Co., Troy, Ohio, has announced a complete new design in its "Weldmobile." It is described as a self-contained, self-propelled welding unit, with engine coupled to the generator, not a tractor with a generator driven through power take-off. By traveling directly to the job and being ready to weld without waiting for

All-State's JET FLUX® and JET FLUX DISPENSER® on production line at Griggs Manufacturing Co. Acetylene and Jet Flux mixed and fed automatically from Dispenser.

to get the best joint, use the right

FLUX

you name it—ALL-STATE has it

ALL-STATE makes quality fluxes for torch and soldering iron applications on all commercial metals . . . in the form you prefer: liquid, paste, powder, flux cored solders, flux coated rods. Working temperatures range from 300F to 2200F. Designed for maximum wetting action, minimum fuming. For instance:

DUZALL . . . a new liquid flux for all soft solders, all metals (except light metals). DUZALL eliminates pre-cleaning, increases capillary action, leaves minimum deposit. Comes in handy 4 oz. refillable dispenser-type plastic containers, and in larger units.

#11 BRAZALOY® . . . a paste or powder flux for use on 14 ferrous and bronze alloys. Wide temperature range: 1200F to 2200F. Non-corrosive, non-fuming. Also available extruded on Nickel Silver welding rods.

#31 BRAZALOY® . . . a highly active aluminum brazing flux that gives maximum wetting action, excellent capillary flow. Protects surfaces from discoloration, requires less after-cleaning. An outstanding temperature indicator.

S200 SILVER BRAZING FLUX . . . melts at 600F, becomes transparent at 1100F, protects heated base metal to 1800F. Induces excellent capillary action and flow of silver alloys.

Send for free copy of 54-page Instruction Manual and for information on custom coating your welding rods.

Distributor-Stocked, convenient to buy. Economical to use.

ALL-STATE WELDING ALLOYS CO., INC., White Plains, N. Y.

Call WHite Plains 8-4646 or write for nearest distributor

For details, circle No. 37 on Reader Information Card

electricians to hook up power lines, the unit is said to save hours of time.

The 400-amp model is powered by a Chrysler 6-cylinder industrial engine and the 600-amp model is powered by a Chrysler V8-cylinder industrial engine. In addition to welding power, the Weldmobile can supply up to 1 kw (100 v dc) auxiliary power.

For details, circle No. 113 on Reader Information Card.

All-purpose Welding Machines

Two all-purpose "Muretran" inert-arc welding machines have been announced by Metal & Thermit Corp., Rahway, N. J. One is an ac-dc machine; the other is ac only. By changing a switch, or by the use of simple plug-in controls, they also can be used for manual, automatic, inert-gas spot or gas-shielded-arc consumable electrode welding.

According to the manufacturer, a special "flux density" control permits remote control of both the a-c and d-c welding currents. A saturable shunt transformer is used. Magnetically controlled, it eliminates the need for a separate saturable reactor. Dual coil windings are said to give balanced output, instant starting voltage, high power factor and wide range stepless current control. High-efficiency silicon rectifiers are used in the ac-dc model.

Both "Muretran" models are described as being equipped with a built-in high-frequency stabilizer, primary line contactor, separate control transformer, thermal overload protection and a 20-ft remote control cable and switch assembly. Both machines reportedly are designed for operation from single-phase 230/460 ac power; each requires 21 kva.

For details, circle No. 114 on Reader Information Card.

New Hi-Impact Plastic Insulated
Panel Receptacles and Mating Plugs

Now, you can make fast, positive power connections to any metal panel or housing without special insulating materials. Simply punch out a hole and insert a Cam-Lok self-insulated Receptacle! Uses standard electrical lock-nuts, affords "dead-front" protection. Push in and twist Cam-Lok mating Plug and you've made a locked connection, which can be released quickly.

New Cam-Lok Receptacles eliminate costs of special insulating panels and reduce assembly time. Patented, high-pressure contact assures minimum resistance and heating.

Cam-Lok has a complete line of Receptacles and Plugs in many sizes and designs. Standard and special purpose Power Distribution Connections are available. Write today for new Bulletin No. 301.

"Dead Front" design for fast
direct mounting on . . .

• ELECTRICAL DISTRIBUTION PANELS • SWITCHGEAR
• BUS DUCT • JUNCTION BOXES
• WIREWAY or any electrical cubicle

cam-lok
DIVISION

EMPIRE PRODUCTS, INC.
P.O. BOX J-98
CINCINNATI 36, OHIO

For details, circle No. 41 on Reader Information Card

NEW! WYPO FILE FREE!

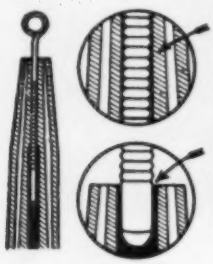
NEW POLISHED ALUMINUM CASE DESIGNED TO SERVE AS HANDLE FOR THE NEW FILE

Let Your Local Welding Supply Dealer Explain Why "YOU GET SO MUCH MORE" With . . .

WYPO
Wipes and Polishes
the World's Finest
CUTTING & WELDING TIP CLEANERS

FREE! NEW, SPECIALLY DESIGNED WYPO POLISHING FILE INCLUDED IN EACH SET

More Exclusive WYPO Features



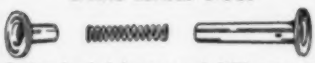
These rounded outer edges of cleaning ridges clean and polish tip orifice without scratching or cutting.

This smooth pilot guides WYPO Tip Cleaner into tip. Will not enlarge or damage tip port.

This cross section view of WYPO Cleaning Surfaces shows these exclusive features: Rounded cleaning surfaces that won't jam or cut.

Straight sided valleys insure thorough cleaning by removing all waste.

SPRING LOADED SPOOL



Spring loaded brass spool. Will not rust. Holds cleaners securely in case.

DOUBLE WOUND EYES

Insures longer life for small sizes of WYPO Tip Cleaners. Will not pull out of case.

STAINLESS STEEL POLISHING FILE

Specially designed WYPO File furnished free in each set

NOW AVAILABLE IN 3 CONVENIENT SETS

WYPO TIP CLEANERS
STANDARD SET

CLEANER NO.	FOR DRILL
7	75-74
8	73-71-71
10	70-69-68
12	67-66-65
14	64-63-62
15	61-60
16	59-58
17	57
18	56
22	55-54
24	53-52
26	51-50-49

S. S. WYPO FILE MADE IN U.S.A. PAT. NOS. 2629581, 2673750 IN CANADA 1948

STANDARD SET OF (12) Cleans (37) Drill Sizes Nos. 75 to 49 Incl.

WYPO TIP CLEANERS
JUMBO SET

CLEANER NO.	FOR DRILL
28	48-47
30	46-45
31	44-43
34	42-41
37	40-39-38
39	37-36
42	35-34-33
44	32-31
45	30

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JUMBO SET OF (9) Cleans (19) Drill Sizes Nos. 48 to 30 Incl.

MASTER SET

CLEANER NO.	FOR DRILL
7	75-74
8	73-72-71
10	70-69-68
12	67-66-65
14	64-63-62
15	61-60
16	59-58
17	57
18	56
22	55-54
24	53-52
26	51-50-49
28	48-47
30	46-45
31	44-43
33	42-41
37	40-39-38
39	37-36
42	35-34-33
44	32-31
45	30

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WYPO TIP CLEANERS PAT. NOS. 2629581, 2673750 IN CANADA 1948

MASTER SET OF (31) Cleans (46) Drill Sizes Nos. 75 to 30 Incl.

Replacement cleaners and files available. Cleaning Range— Cleaner No. & Drill Nos. stamped on back of each case. WYPO GIVES YOU MORE!

SOLD BY LEADING WELDING SUPPLY DEALERS

MAITLEN AND BENSON, INC.
1395 Obispo St., Long Beach 4, Calif.

For details, circle No. 42 on Reader Information Card

Gageless Regulators

Two-stage gas pressure regulators without the conventional glass covered gages are being marketed by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. Available for both oxygen and acetylene cylinder use in welding, heating or cutting operations, the regulators reportedly

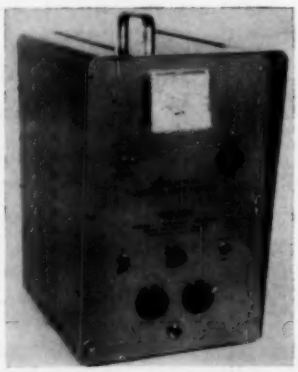
are particularly useful where extremely rough usage is encountered.

Delivery pressures, are said to be set with a micrometer type indicator; two ranges of regulation are available by means of low–high markings on the adjusting knob and lines on the spring case. The gages are also equipped with a cylinder pressure indicator at the top of the regulator and protected from damage by a forged brass housing.

For details, circle No. 121 on Reader Information Card.

Stored Energy Power Supply

A 100 watt-second stored energy welding power supply designed especially for the electronic component packaging field has been developed by the vacuum tube products division of Hughes Aircraft Co., Florence Ave. & Teele St., Culver City, Calif.



The power supply is designated model VTW-30 and reportedly delivers a step-free, adjustable range of power of 0.5 to 100 watt-seconds. According to the manufacturer, a pulse width of less than $1\frac{1}{2}$ msec assures no burning or discoloration of the weld area and no heat damage to the components being welded.

For details, circle No. 116 on Reader Information Card.

3 BIG REASONS WHY SO MANY WELDERS HAVE SWITCHED TO HI-AMP® ELECTRODE HOLDERS

1- Wrap around Glass Fibre Tip Insulation—30% more heat resistant than any other make.

2- Brilliant Red Tips and Trigger-Bright Yellow Handle—all Glass Fibre, an outstanding Safety Feature.

3- Body completely insulated—no bare spots.

Just ask your Welding Supply Dealer for PROOF of the above statements.

LENCO, Inc.
JACKSON, MISSOURI
Weld with HI-AMP

For details, circle No. 30 on Reader Information Card

Only **$110** for 3,000 lb. model

New Gauge Measures Welding ELECTRODE FORCE

Rugged all mechanical design—no leaky hydraulic units or sensitive electrical circuits to cause trouble.

In multiple gun welding presses several load cells can be set in position and force read with only a single dial indicator.

Design of load cell (only ⅝" between load points) is ideal for checking electrode force, as well as setup and maintenance of other mechanical or hydraulic equipment.

INSTRUMENT CONTROL CO.
1554 Nicollet Avenue
Minneapolis 3, Minnesota

For details, circle No. 40 on Reader Information Card

SILVER BRAZING SIMPLIFIED NOW, WITH FIRST FLUX-COATED ROD!

EutecSil® 1020 FC*... first flux-coated silver alloy ever available...new concept, new combination from core to coat... a fresh success from Eutectic's research. Biggest news is in the benefits to weldors: *no more fluxes to mix, apply, dry!* Flux always present in right amount. Ferrous, non-ferrous metals, joined equally well. Highest fluidity, lowest melting point, greatest strength. And more...

BENEFITS NEVER END...In addition to easier application and all the other features listed above, EutecSil 1020 FC is non-toxic: you can use it on food equipment. Also, it contains a built-in oxide remover. And EutecSil 1020 FC does not deteriorate. Unique flux eliminates "stub loss" between rods. Add to these advantages the fact that you stock only one product instead of two yet get a better joint, and you see why EutecSil 1020 FC... the latest "first" from Eutectic's research...is the greatest news of the year for weldors.

®Reg. T. M. Eutectic Welding Alloys Corp. *Patent pending

Please send complete literature on EutecSil 1020 FC

NAME..... MY TITLE..... COMPANY.....

ADDRESS..... CITY.....ZONE.....STATE.....

EUTECTIC WELDING ALLOYS CORPORATION

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Originator of the Low Heat Input process... The ONLY welding alloy manufacturer in the world capable of producing welding rods and electrodes from virgin metals to finished products in ANY metal.

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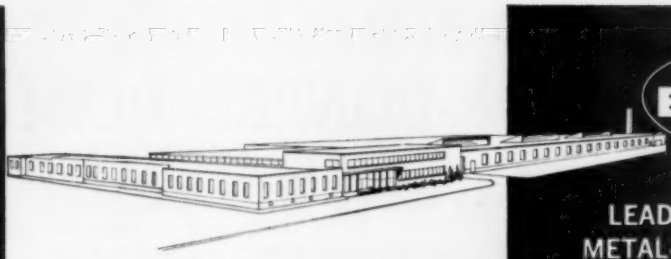
PRESIDENT
R. D. WASSERMAN



ORIGINAL
Low Temperature ®
EUTECTIC
WELDING ALLOYS

LEADS THE WORLD IN
METAL-JOINING PROGRESS

Chemists, Metallurgists, Welding Technicians

Join our expanding research staff...

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SUPPLEMENT TO THE WELDING JOURNAL, NOVEMBER 1960

The Heat-Affected Zone of Arc-Welded Ductile Iron

Investigation aimed at studying the effect of the cooling rate of various regions of a weldment on the formation of martensite and massive carbides and the redeposition rate of carbon on existing graphite spheroids during cooling

BY E. F. NIPPES, W. F. SAVAGE AND W. A. OWCZARSKI

ABSTRACT. The ductile irons combine the casting advantages of gray-cast iron with the strength, ductility and toughness of mild steel. Fusion welding of ductile irons produces many complex reactions which may create a heat-affected zone containing numerous constituents, including brittle ones, such as martensite and massive carbides. The presence, quantity and distribution of the brittle constituents depend on the analysis of the material, the previous history and matrix of the material, the peak temperature attained during any specific thermal cycle and the rate of cooling from this peak temperature through the critical transformation-temperature regions.

By using the RPI synthetic-specimen technique involving a high-speed, time–temperature control device, specimens of finite dimension can be prepared which duplicate the microstructure of any specific region in an arc-weld heat-affected zone. These specimens can be subsequently examined and mechanically tested to determine the properties that are peculiar to the thermal cycle associated with that particular region.

Applying the synthetic-specimen technique to the study of ferritic ductile iron of a specific chemistry revealed that definite microstructural changes first occurred when the peak temperature of the weld thermal cycle exceeded 1550° F. Thermal cycles with peak temperatures up to 2200° F could be investigated; with thermal cycles with peak temperatures above 2200° F, the test specimens melted. The use of a preheat temperature of 800° F, the maximum employed in this investigation, prevented the formation of massive carbides and martensite in regions which reached peak temperatures up to 2000° F. Above a peak temperature of 2000° F, carbides, predominantly intergranular in nature, persisted in the microstructure, even with an 800° F preheat. Large areas of a eutectic structure, which formed upon solidification of a liquid phase, were also present in samples experiencing a thermal cycle with a peak temperature of 2100° F. With preheat temperatures of 400° F and above, secondary spheroids of graphite formed in areas where the liquid phase had appeared.

Mechanical tests indicated that the average hardness increased from approximately Rockwell A 47 (VPN 140) for the as-received material, to Rockwell A 50 (VPN 153) with a thermal cycle having a 1550° F peak temperature, to Rockwell A 78 (VPN 580) with a 2200° F peak temperature. With slower cooling rates which favored reprecipitation of graphitic carbon onto spheroids and favored austenite-to-pearlite transformation, microstructures with lower hardnesses resulted for each peak temperature investigated.

The results of this investigation limited to one carbon-silicon-manganese-nickel chemistry, substantiate existing evidence which recommends avoiding fusion of the base metal because of the resulting embrittlement. Heat-affected-zone microstructures, which showed no evidences of melting, apparently retain considerable toughness with proper control of heat input and cooling rate. This suggests, in this instance, the use of such processes as braze welding or arc welding utilizing electrodes whose deposited compositions have melting points of the order of 2000° F.

E. F. NIPPES, W. F. SAVAGE and W. A. OWCZARSKI are associated with the Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, N. Y.

Introduction

The ductile irons are a family of ferrous metals containing magnesium. The retention of a small amount of magnesium results in the formation of spheroidal graphite rather than flakes of free graphite directly in the molten metal and upon its solidification. The result of this spheroidal-graphite distribution in a steel-like matrix is a tough and ductile material, similar in properties to cast low-carbon steels. Ordinary gray-cast iron contains a flake-like distribution of graphite in a ferrite-pearlite matrix. The flake-like

Table 1—Chemical Composition of Ductile Iron Investigated

Carbon, %	3.05
Silicon, %	2.60
Manganese, %	0.26
Phosphorus, %	0.021
Nickel, %	2.10
Sulfur, %	0.011
Magnesium, %	0.072

Table 2—Typical Mechanical Properties of Fully Ferritic Unalloyed Ductile Iron

Tensile strength, psi	60,000–80,000
Yield strength, psi	45,000–60,000 (0.2% offset)
Elongation, %	15–25
Hardness, Bhn	140–200 (48–57 Rockwell A)

Table 3—Range of Chemical Composition of Unalloyed Commercially Produced Ductile Irons

Carbon, %	2.0–4.8
Silicon, %	0.50–6.0
Manganese, %	0.0–0.80
Phosphorus, %	0.0–0.08
Sulfur, %	0.005–0.015

graphite severely disrupts the continuity of its matrix and, as a consequence, is the cause of the weakness and brittleness which is characteristic of gray-cast iron.

The thermal cycles experienced by ductile iron during an arc-welding process may have a very damaging effect on the properties of the heat-affected zone.[1] This effect is due to the presence of the free graphite which tends to dissolve at elevated temperatures into the austenitized matrix. The high-carbon-containing constituents thus formed may appear as brittle martensite if cooling rates are fast enough. Some of the dissolved carbon may also reprecipitate as secondary graphite on the existing spheroids during cooling; however, some of the dissolved carbon may precipitate as massive carbides which can have a marked embrittling effect.

It was the aim of the present research to study the effects of weld thermal cycles on a ductile iron whose matrix was almost completely ferritic (95% ferrite, 5% pearlite). Specifically, the program was concerned with the effect of the peak temperature and cooling rate of various thermal cycles of the microstructure and hardness of the associated heat-affected regions. The technique used to evaluate these factors was developed in the Welding Laboratory at Rensselaer Polytechnic Institute.[2,3] This synthetic-specimen technique involves the use of a time–temperature control device which duplicates weld thermal cycles in specimens of significant size for subsequent testing.

Scope

This investigation was a preliminary study of the effects of weld thermal cycles on a ductile iron using the synthetic-specimen technique as the means of approach. It was the intention of the investigators to study the effect of the cooling rate of various regions of a weldment on the formation of martensite and massive carbides and the redeposition rate of carbon on existing graphite spheroids during cooling. The effect of weld thermal cycles on the hardness and the correlation between microstructure and hardness were examined briefly.

Material

The material used in this investigation was supplied in the fully annealed condition. A typical full-annealing or ferritizing heat treatment consists first of heating to 1650° F for 1 hr plus 1 additional hour for each inch of section thickness. Then the material is furnace cooled to 1275° F, held for 5 hr plus 1 additional hour for each inch of section thickness, and finally cooled to room temperature by any convenient means.[4] The microstructure (Fig. 5) of the fully ferritized ductile iron revealed less than 5% pearlite, with the remainder ferrite and spheroidal graphite. The pearlite which was present in these specimens had been partially spheroidized by the annealing treatment.

The composition of the ductile iron used in this investigation is shown in Table 1. Typical mechanical properties of this grade are listed in Table 2. It is worth noting that the chemistry studied represents only one of the many combinations possible and commercially produced within the ranges listed in Table 3.

Apparatus

A high-speed time-temperature controller[2] was used in this investigation to synthesize the rapid thermal cycles associated with the heat-affected zones of arc welds. The specimen to be treated is held in a pair of water-cooled copper jaws, the free length between jaws being held constant at approximately 1 in. The specimen is heated by its own resistance to the flow of current from the secondary of a transformer.

A 0.010-in. chromel-alumel thermocouple, percussion welded to the specimen at a point midway between the water-cooled jaws, provides a signal proportional to the instantaneous specimen temperature. This feed-back signal is compared with a reference signal obtained from a cam-operated potentiometer. From this error signal, the current required to restore the specimen to the desired instantaneous temperature is automatically and proportionately controlled 60 times per second. Thus, if the specimen temperature is momentarily lower than the desired instantaneous temperature, as determined by the output of the cam-controlled potentiometer at that instant, the primary of the transformer is energized. If the specimen temperature is instantaneously higher than the desired temperature, the control functions to de-energize the transformer and the specimen is allowed to cool by conduction of heat longitudinally to the water-cooled copper jaws. The basic sensitivity of the time–temperature control obtained in this way is such that a departure of the instantaneous specimen temperature from the desired value by ±3° F is sufficient to produce corrective action by the control device. The desired thermal

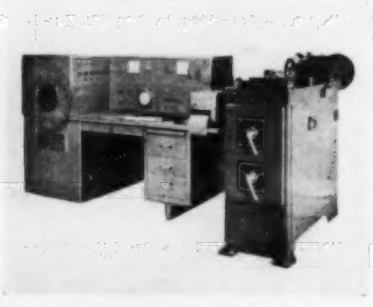

Fig. 1—Over-all view of high-speed time-temperature control device

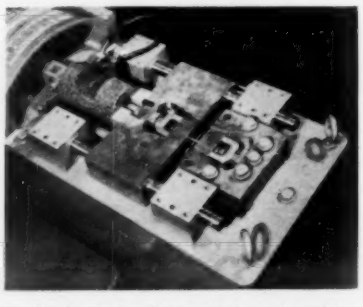

Fig. 2—Close-up of sample in test position for simulation of weld thermal cycle

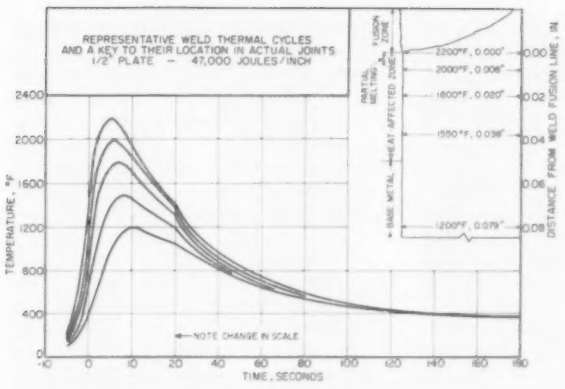

Fig. 3—Representative weld thermal cycles and a key to their location in actual joints, $^1/_2$-in. plate, 47,000 joules/inch

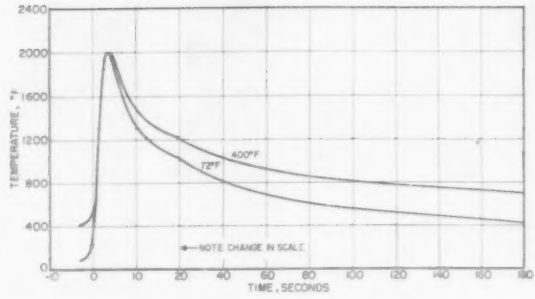

Fig. 4—Effect of initial plate temperature on weld thermal cycle, $^1/_2$-in. plate, 47,000 joules/inch

cycle is thus programmed by a readily constructed sheet-metal cam which determines the output of the cam-controlled potentiometer. Figure 1 shows an over-all view of the high-speed, time–temperature control device. Figure 2 shows a close-up of a sample in test position in the water-cooled copper jaws.

By means of this equipment and its associated techniques, the microstructure at any desired point in the heat-affected zone can be reproduced in a specimen. The size of the accurately and uniformly heat-treated section of these specimens is such that testing may be accompanied by conventional techniques. Thus, with this synthetic-specimen technique, the properties of any desired point in the weld heat-affected zone may be determined.

Procedure

The technique used to duplicate weld thermal cycles during this investigation has already been described in detail in recent publications.[5] Conditions simulating a weld deposit on $^1/_2$-in. thick plate[6] using a $^3/_{16}$-in. electrode and an energy input of 47,000 joules/in. (approximately 24 arc volts, 200 amp and 6 ipm travel speed) were chosen for this research. However, not all electrodes operate with such a high input; for instance, a $^1/_8$- or $^5/_{32}$-in. diam E NiFe electrode would be used with a somewhat lower energy input for $^1/_2$-in. plate. In order to determine the effect of preheat temperatures, thermal cycles were chosen to simulate initial plate temperatures of 72, 210, 400, 600 and 800° F. The peak temperatures of the thermal cycles initially chosen were 1200, 1400, 1550, 1800, 2000, 2100 and 2200° F. Figure 3 contains a graphic representation of several of the thermal cycles used, and, in addition, the regions in the heat-affected zone which realize these thermal cycles are located schematically in this figure. Figure 4 shows the effect of preheat on a representative thermal cycle with a peak temperature of 2000° F resulting from an energy input of 47,000 joules/in. in $^1/_2$-in. plate.

Specimens, machined into blanks 0.42 x 0.42 x 3 in., were subjected to thermal cycles, as outlined above. The "heat-treated" ductile-iron blanks were prepared for metallographic examination. These specimens were sectioned transversely at the midpoint of their length, that is, at the center of the region which had experienced the thermal cycle.

Following metallographic examination, the gross hardness of the specimens was determined by averaging the results of at least 3 tests per specimen using the Rockwell "A" hardness scale. With this scale, the indentor covered a sufficiently large area of the matrix so that a representative hardness reading would be obtained. Optical examination showed that each indentation usually enclosed of the order of 6 to 10 graphite spheroids. The size of the indentation was an important consideration in view of the drastic difference in hardness of the constituents present. Had a small indentation been made, the probability of indenting only a very hard or very soft portion of the matrix would be much greater. Thus, the possibility of scatter and error would also be greater.

Results

The results of this investigation are presented in two sections: microstructure and hardness. The first section on microstructure describes and illustrates how the weld thermal cycles influence the metallographic structure of the ductile-iron specimens studied, while the second section presents some of the effects of these microstructural changes on the base-metal hardness. Table 4 summarizes the results of the experimental portion of this investigation.

Microstructure

Most of the information resulting from this investigation comes from careful study of the metallographic structures. The photomicrographs, Figs. 5–26, reveal the structures of the as-received ductile iron and of the heat-affected zone at various selected distances from the weld fusion zone.

Peak temperatures of 1200° F, as illustrated in Fig. 6, and 1400° F produced no structural changes. With thermal cycles having a peak temperature of 1550° F, some intergranular penetration, appearing as massive grain-boundary carbide, is evident, as shown in Figs. 7, 8 and 9. The higher diffusion rate of carbon in the grain boundaries is the cause of this preferential penetration of the carbon during the thermal cycle.

With 1800° F peak temperatures, as seen in Figs. 10 to 14, intergranular penetration extends farther away from the spheroids and deeper into the matrix. Furthermore, with this peak temperature, the first evidence of martensite can be found, as illustrated in Fig. 10. Here the carbon content of the matrix has been sufficiently enriched during austenitization, and as a result of the rapid cooling rates, martensite formed.

As may be seen by examination of Figs. 15 to 19, specimens subjected to thermal cycles with peak temperatures of 2000° F contain larger amounts of martensite or pearlite

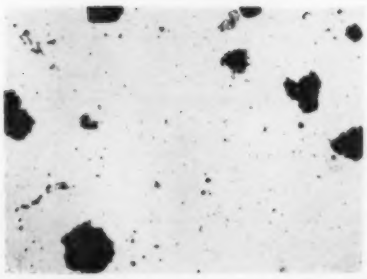

Fig. 5—Microstructure of as-received ductile iron, fully ferritized, as-polished. X 250. (Reduced by 1/2 upon reproduction)

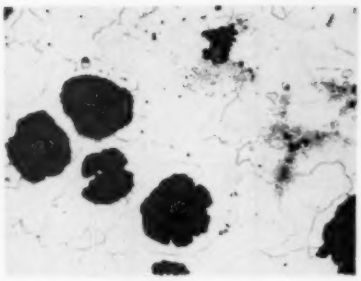

Fig. 6—Microstructure of specimen experiencing a thermal cycle with a 1200° F peak temperature, 72° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

and more of the massive intergranular carbides. Some ferrite is still present in these microstructures but it exists only at positions far removed from the graphite spheroids, where the carbon content has not been increased by diffusion during the thermal cycle.

As a result of exposures to thermal cycles with peak temperatures of 2100° F, partial liquefaction occurred, appearing as eutectic structure near the graphite spheroids in Figs. 20 to 24. Only traces of ferrite can be found in the microstructure of these specimens, the matrix now being composed mainly of martensite or pearlite, carbides and eutectic. In Figs. 20 and 21, the dark-etching constituent which appears near the edges of the eutectic areas is believed to be a very finely laminated pearlite.

The specimen exposed to a peak temperature of 2200° F, Figs. 25 and 26, contained a considerable amount of eutectic structure as well as large voids which were the result of liquefaction. The white phase surrounding the graphite, as illustrated particularly in Fig. 26, is ferrite (see also Figs. 22–25). At a peak temperature of 2200° F, only specimens duplicating an initial plate temperature of 72° F were successfully prepared; complete melting occurred in specimens duplicating initial plate temperatures of higher values.

As shown in Fig. 27, higher values of initial plate, or preheat, temperature lower the cooling rates in the heat-affected zone. For thermal cycles which produced austenite of high-carbon content (peak temperature greater than 1550° F), martensite, but no newly-transformed pearlite, was evident in the higher carbon regions of the matrix for initial plate temperatures of 72° F, Figs. 10, 15 and 20. However, with the slower cooling rate provided by a preheat of 210° F, some pearlitic transformation products occurred, Figs. 11, 16 and 21. With 400° F preheat, a greater proportion of the martensite and carbides was replaced by pearlite (Figs. 12, 17 and 22), and with 600° F preheat (Figs. 13, 18 and 23) virtually all martensite was replaced by the pearlite. With an 800° F initial plate temperature, Figs. 14, 19 and 24, all martensite transformation was prevented and none appeared in the microstructure of the specimens investigated.

Expressed as a cooling rate, the "critical" cooling rate to avoid martensite completely is about 6.3° F/sec, measured at 1300° F. However, in specimens duplicating higher peak temperatures, such as 2100° F, Figs. 20–24, the massive carbides remained in the microstructure along with the eutectic structure. An increase in the initial plate temperature from 400 to 800° F increased the intergranular carbides in the 2100° F series, Figs. 22–24.

In the 2100° F series with the slow-cooling rates associated with preheats of 400° F and above Figs. 22–24, secondary spheroids of graphite were formed in that portion of the structure which had been liquefied. These secondary-graphite spheroids, having a smaller diameter than primary spheroids, can be seen well in the specimen experiencing a thermal cycle with a 2200° F peak temperature, Figs. 25 and 26.

Hardness

The results of the hardness study are presented in Table 4 and Figs. 28 and 29. Figure 28 illustrates that the hardness increases with increasing peak temperatures to a maximum hardness at 2200° F peak, above which 100% liquid phase occurs. In Fig. 29 the hardness values for the various peak temperatures are plotted as a function of the initial plate temperature. For each peak temperature, an increase in preheat temperature results in a decrease in hardness value. The hardness data correlate well with the structures presented in the previous section. In general, an increase in hardness can be associated with a decrease in toughness.

Discussion

Analysis of the transformations and transformation products that could be formed in the heat-affected zone of the ductile irons is not simple. The graphite spheroids provide sources from which carbon can dissolve and diffuse into the matrix during thermal treatments. It is

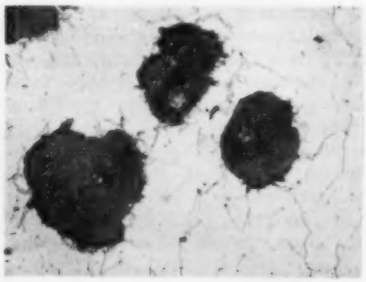

Fig. 7—Microstructure of specimen experiencing a thermal cycle with a 1550° F peak temperature, 72° F initial plate temperature. Nital etch. X 500. (Reduced by 1/2 upon reproduction)

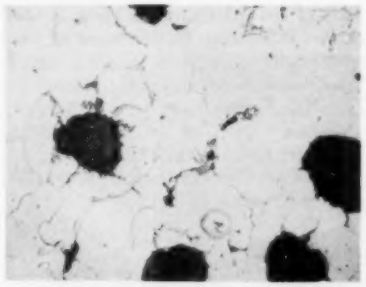

Fig. 8—Microstructure of specimen experiencing a thermal cycle with a 1550° F peak temperature, 400° F initial plate temperature. Nital etch. X 500. (Reduced by 1/2 upon reproduction)

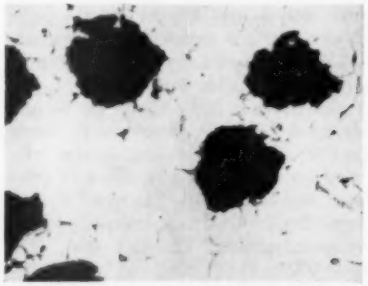

Fig. 9—Microstructure of specimen experiencing a thermal cycle with a 1550° F peak temperature, 600° F initial plate temperature. Nital etch. X 500. (Reduced by 1/2 upon reproduction)

then possible to theorize that the resulting concentration gradients of carbon, coupled with the rapid heating and cooling rates associated with weld thermal cycles, may result in an almost infinite variety of compositions and microstructures; in addition, such elements as manganese, nickel, chromium, phosphorus and, most of all, silicon will affect the presence, absence or properties of these constituents. Each of the structures and compositions formed possesses its own hardenability and responds to the cooling portion of the weld thermal cycles accordingly. Udin[7] has presented some theoretical considerations on the constituents found in the heat affected zone in a previously published paper. However, this study added little to the quantitative knowledge of the weldability of ductile irons. The purpose of the present investigation is to provide more quantitative information in this area.

As previously noted, transformation of austenite to martensite in the heat-affected zone could be avoided by cooling at a rate of 6.3° F per sec (measured at 1300° F). This corresponds to the "critical" cooling rate of the most hardenable austenite composition that was formed during the thermal cycles. With cooling rates slower than this, pearlite-ferrite structures will be formed upon decomposition of the austenite. In the extreme case of slow cooling, the dissolved carbon may reprecipitate upon the graphite spheroids, producing a fully ferritic structure.

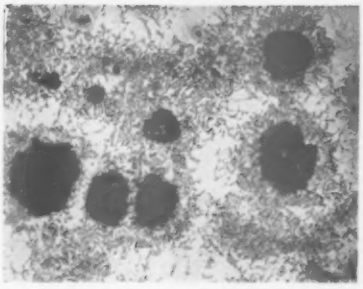

Fig. 10—Microstructure of specimen experiencing a thermal cycle with a 1800° F peak temperature, 72° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

The amount of martensite or pearlite in the matrix is mainly dependent upon the peak temperature reached, in that the higher the peak temperature, the greater the amount of these transformation products. The amount of martensite or pearlite in the matrix increases with increasing peak temperature because of the higher carbon concentration which can be attained even at greater distances from the graphite spheroids. These higher-carbon concentrations are a result of the increase in diffusion rate of carbon in the iron-silicon matrix with an increase in temperature. The preferential diffusion of carbon along grain boundaries at lower temperatures is evidenced by the appearance of grain boundary carbides (Fig. 7) at peak temperatures below which martensite and pearlite are observed in the matrix adjacent to the graphite.

Table 4—Summary of Results of Thermal Cycles Studied

Peak temp., °F	Initial plate temp., °F	Approximate cooling rate, °F/sec at 1000° F	Approximate cooling rate, °F/sec at 1300° F	Hardness, Rockwell A	Microstructure, Fig. no.
As-received		...	...	47.3	5
1200	72	...	...	47.3	6
1550	72	15	47	48.9	7
1550	400	7	24	49.5	8
1550	600	2.3	14.6	50.6	9
1800	72	15	47	53.6	10
1800	210	12	34	53.0	11
1800	400	7	24	52.7	12
1800	600	2.3	14.6	51.6	13
1800	800	0.8	6.3	51.7	14
2000	72	15	47	62.0	15
2000	210	12	34	61.8	16
2000	400	7	24	58.1	17
2000	600	2.3	14.6	60.5	18
2000	800	0.8	6.3	56.1	19
2100	72	15	47	72.7	20
2100	210	12	34	70.7	21
2100	400	7	24	68.4	22
2100	600	2.3	14.6	69.1	23
2100	800	0.8	6.3	67.4	24
2200	72	15	47	77.5	25, 26

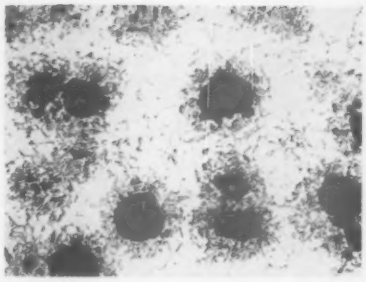

Fig. 11—Microstructure of specimen experiencing a thermal cycle with a 1800° F peak temperature, 210° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

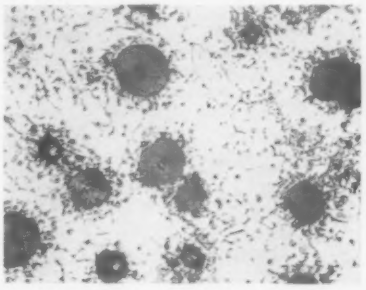

Fig. 12—Microstructure of specimen experiencing a thermal cycle with a 1800° F peak temperature, 400° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

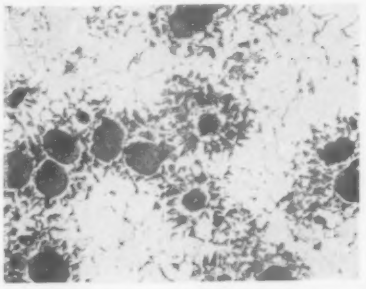

Fig. 13—Microstructure of specimen experiencing a thermal cycle with a 1800° F peak temperature, 600° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

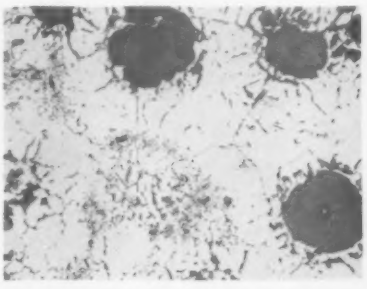

Fig. 14—Microstructure of specimen experiencing a thermal cycle with a 1800° F peak temperature, 800° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

Complete absence of massive carbides (other than pearlitic carbides) was never realized for any heat-affected-zone microstructure investigated. In the regions which reached higher peak temperatures (2100° F, as in Figs. 20–24), there were considerable quantities of massive carbides, the relative amounts of which increased with increasing preheat temperatures. At lower peak temperatures, the carbides were not as massive along the grain boundaries; however, some pearlite was observed near the boundaries with 400–600° F preheat (as in Fig. 8). Here the grain-boundary carbon probably diffused into the matrix in sufficient quantity, due to the longer time at austenitizing temperatures, to permit the formation of high-carbon austenite. This austenite in turn transformed to pearlite on cooling at the relatively slow-cooling rates associated with these values of preheat.

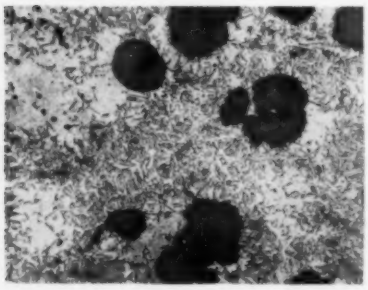

Fig. 15—Microstructure of specimen experiencing a thermal cycle with a 2000° F peak temperature, 72° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

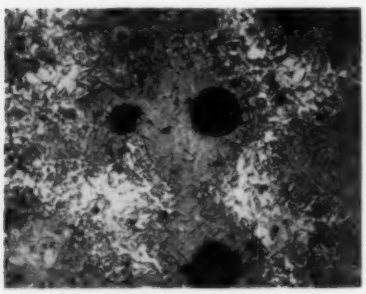

Fig. 16—Microstructure of specimen experiencing a thermal cycle with an 2000° F peak temperature, 210° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

The presence of a liquid phase, resulting from exceeding the solidus temperature, was evident from the eutectic structure present in samples experiencing a peak temperature of 2100° F or above. The cooling rates were too rapid to permit the decomposition of this eutectic as it cooled through the range between solidification and the temperature below which the diffusion of carbon is sluggish. However, with higher-preheat temperatures, some of the liquid did reprecipitate graphitic carbon on cooling as secondary spheroids which were smaller than the original graphite spheroids. In spite of the fact that these secondary-graphite spheroids formed, the major portion of the eutectic structure persisted in these heat-affected zone microstructures, as in Figs. 22–26.

The practical importance of the structural changes lies in their effect on the mechanical and engineering properties of the heat-affected material. The synthetic-specimen technique lends itself very well to the study of these mechanical properties and property changes. In this investigation, the hardness was studied in a limited, introductory fashion. As expected, the hardness of the thermally treated ductile iron increased with increasing peak temperature for specimens with initial plate temperature of 72° F (Fig. 28). With the higher-peak temperatures, greater amounts of martensite and massive carbides replaced soft ferrite resulting in a net hardness increase. With increasing preheat temperature, more of the martensite was replaced by pearlite and some of the grain-boundary carbides decomposed to austenite from which pearlite also resulted. These microstructural changes resulted in some reduction in hardness of the heat-affected zone with increase in preheat for each peak temperature tested, as is illustrated in Fig. 29.

The data thus far have confirmed that the heat-affected zone of arc-welded ductile iron of chemistry and microstructure tested will not be entirely free of a hard region. The results also confirm that moderate preheat temperatures can reduce the hardness in regions which do not reach the melting temperature. Further investigation of the effects of different thermal cycles on the mechanical properties of the heat-affected zone could produce a set of parameters which would minimize embrittlement. For example, moderate postheat treatment, such as a commonly practiced 1200° F max. stress relieving, can be helpful in further reduction in hardness. Obviously the extreme postheat treatment, the full anneal, will eliminate carbides and martensite, but shorter, lower temperature heat treatments could reduce the hardness by a considerable extent. The postheat treatment of subsequent arc passes could also be studied in this relation.

The limited scope of this investigation prevented the accumulation of a large amount of data. However, the possibility of further pursuit of the synthetic-specimen technique to a more thorough analysis of the mechanical properties of thermally-affected ductile irons of various chemistries has been introduced.

Conclusions

1. The synthetic-specimen technique of studying arc-welding heat-

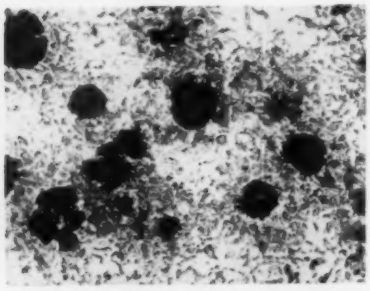

Fig. 17—Microstructure of specimen experiencing a thermal cycle with a 2000° F peak temperature, 400° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

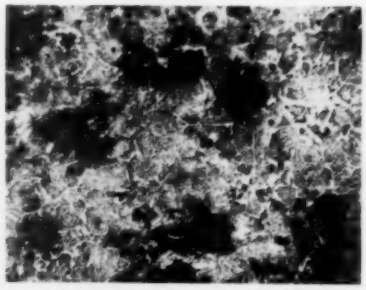

Fig. 18—Microstructure of specimen experiencing a thermal cycle with a 2000° F peak temperature, 600° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

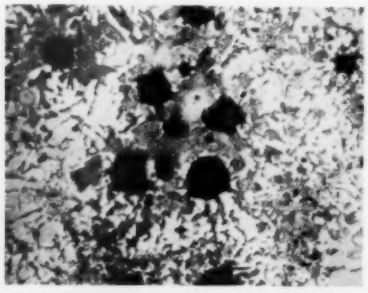

Fig. 19—Microstructure of specimen experiencing a thermal cycle with a 2000° F peak temperature, 800° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

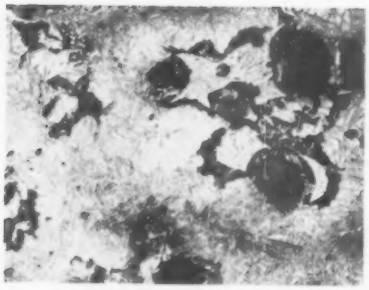

Fig. 20—Microstructure of specimen experiencing a thermal cycle with a 2100° F peak temperature, 72° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

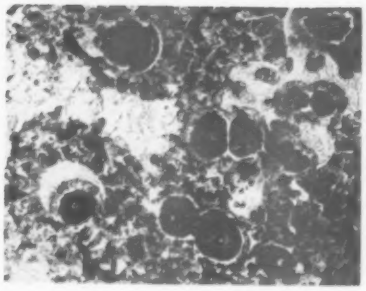

Fig. 22—Microstructure of specimen experiencing a thermal cycle with a 2100° F peak temperature, 400° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

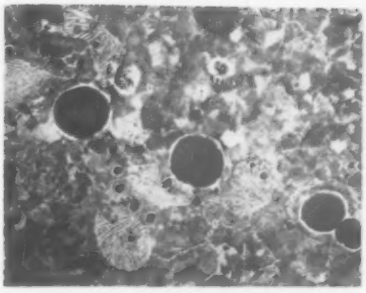

Fig. 24—Microstructure of specimen experiencing a thermal cycle with a 2100° F peak temperature, 800° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

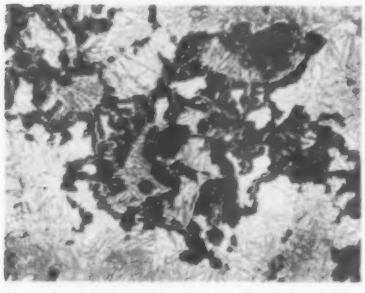

Fig. 21—Microstructure of specimen experiencing a thermal cycle with a 2100° F peak temperature, 210° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

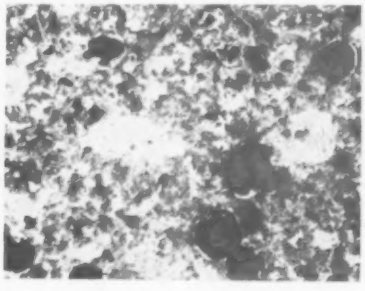

Fig. 23—Microstructure of specimen experiencing a thermal cycle with a 2100° F peak temperature, 600° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

affected zones is ideal for analyzing the thermal effects of welding on the structure and mechanical properties of ductile irons.

2. The formation of martensite and carbides in the heat-affected zone is not easily avoided by simple use of moderate preheats.

3. Martensite formation was eliminated at all peak temperatures studied with an 800° F initial plate temperature. These welding conditions correspond to a cooling rate of 6.3° F per sec measured at 1300° F.

4. The disposal of carbides was not completely realized, even with an 800° F initial plate temperature. At peak temperatures up to and including 2000° F, virtually all the massive carbides were replaced by pearlite. However, with a 2100° F peak temperature, massive carbides appeared in the matrix in addition to the eutectic structure at all preheat values tested.

5. The ductile iron studied was not referritized to any appreciable degree by preheats even as high as 800° F.

6. The hardness of the heat-affected zone increased with increasing peak temperature up to a maximum at the temperature of complete melting. However, at any peak temperature, the hardness decreased with increasing preheat, with a greater rate of hardness decrease occurring at higher peak temperatures.

7. The appearance of a liquid phase at peak temperatures of 2100° F and above, greatly reduces the

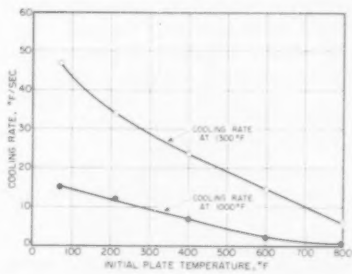

Fig. 27—Cooling rates at 1300° F and 1000° F as a function of initial plate temperature for an energy input of 47,000 joules/inch

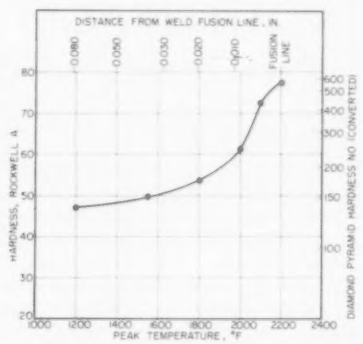

Fig. 28—Hardness of the heat-affected zone as a function of peak temperature and distance from fusion line for 1/2-in. plate welded with an energy input of 47,000 joules/inch

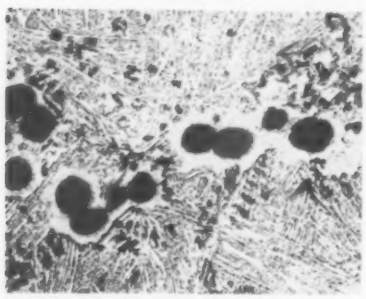

Fig. 25—Microstructure of specimen experiencing a thermal cycle with a 2200° F peak temperature, 72° F initial plate temperature. Nital etch. X 250. (Reduced by 1/2 upon reproduction)

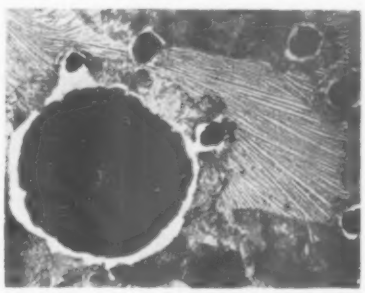

Fig. 26—Microstructure of specimen experiencing a thermal cycle with a 2200° F peak temperature, 72° F initial plate temperature. Nital etch. X 1000. (Reduced by 1/2 upon reproduction.

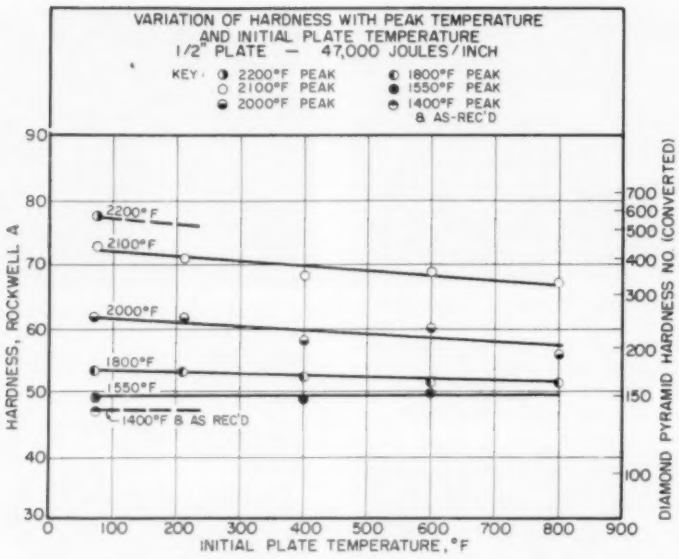

Fig. 29—Variation of hardness with peak temperature and initial plate temperature, 1/2-in. plate, 47,000 joules/inch

possibility of avoiding a brittle structure. The massive carbides and eutectic structure are much more difficult to eliminate than products formed as a result of lower peak temperatures.

8. Secondary spheroids of graphite appeared only in eutectic areas, which indicates that graphite precipitation occurred directly from the liquid phase.

Suggestions for Further Research

As shown in Table 3, the range of chemical compositions for unalloyed and alloyed ductile irons is wide. A study similar to the one just completed but covering a number of carbon-silicon levels should cast light on the most weldable ductile irons.

A thorough analysis of the effects of thermal cycles on the mechanical properties of the heat-affected zone is the next step in the study of the weldability of ductile irons. The mechanical property of particular interest is the toughness which is generally measured by impact testing. Testing of regions of the simulated heat-affected zones that have been subjected to various thermal cycles could reveal the region of minimum toughness. Knowing this, the use of combinations of preheat and post-heat as practical methods of improving the properties of the heat-affected zone to more desirable levels could be investigated. Thermal cycles simulating a second-pass weld could also be investigated to determine the effects of the tempering action on the toughness. The study of these parameters would provide useful information for securing a tough heat-affected zone in arc-welded ductile irons.

Acknowledgment

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Bibliography

1. Pease, G. R., "The Welding of Ductile Iron," WELDING JOURNAL, **39** (1), Research Suppl., 1-s to 9-s (1960).

2. Nippes, E. F., and Savage, W. F., "Development of Specimen Simulating Weld Heat-Affected Zones," *Ibid.*, **28** (11), Research Suppl., 334-s to 546-s (1949).

3. Nippes, E. F., and Savage, W. F., "Tests of Specimens Simulating Weld Heat-Affected Zones," *Ibid.*, **28** (12), Research Suppl., 556-s to 564-s (1949).

4. Savage, R. E., "Heat Treating Ductile Iron," *Steel*, The Metal Working Weekly (November 1955).

5. Nippes, E. F., "The Weld Heat-Affected Zone," 1958 Adams Lecture, THE WELDING JOURNAL, **38** (1), Research Suppl., 1-s to 18-s (1959).

6. Nippes, E. F., Merrill, L. L., and Savage, W. F., "Cooling Rates in Arc Welds in 1/2-in. Plate," *Ibid.*, **28** (11), Research Suppl., 556-s to 564-s (1949).

7. Hucke, E. E., and Udin, H., "Welding Metallurgy of Nodular Cast Iron," *Ibid.*, **32** (8), Research Suppl., 378-s to 385-s (1953).

RESEARCH NEWS

Brazing Research

Development of Partially Volatile Brazing Filler Alloys for High-temperature Application and Resistance to Oxidation, W. M. Lehrer and H. Schwarztbart, Armour Research Foundation of Illinois Institute of Technology for Wright Air Development Center, U. S. Air Force, Dec. 1959, 45 pages. (Order PB 161746 from OTS, U. S. Department of Commerce, Washington 25. D. C., $1.25). Experimental brazing filler alloys were developed containing temperature depressants which can be volatilized during the brazing of stainless steel to leave joints of high remelt temperature. With alloys containing nickel, chromium, germanium, iron, lithium and phosphorus, the two main mechanisms used were dissolution of the base metal in the filler metal and diffusion of constituents of the filler metal into the base metal, and volatilization of the filler metal constituents.

Welding Techniques

Welding of High-strength Steels for Aircraft and Missile Applications (DMIC Report 118), H. W. Mishler and others, Defense Metals Information Center, Battelle Memorial Institute, Oct. 1959, 93 pages. (Order PB 151074 from OTS, U. S. Department of Commerce, Washington 25, D. C., $2.25.) The numerous high-strength steels being used in aircraft and missiles may be welded by most of the usual processes, but a variety of techniques must be used so that the weld joints will be sound and of a strength approaching that of the parent metal. This report is a survey of the techniques currently used. There are separate discussions on low-alloy martensitic steels, hot-work die steels, martensitic stainless steels, and precipitation-hardening stainless steels. In addition, there is a discussion on design considerations and testing and inspection techniques. The information was obtained from interviews, reports, and technical papers.

Welding of Nickel-Chromium-Iron Alloy for Nuclear-Power Stations

New nickel-chromium-iron alloy covered electrode and inert-gas-shielded filler wire developed to meet the rigid welding standards set for nuclear-power station applications

BY C. E. WITHERELL

ABSTRACT. The resistance of the 15% chromium, 7% iron, nickel alloy to stress-corrosion cracking has stimulated the nuclear-power field to consider extensive use of this alloy for components of nuclear-power stations. The fabrication for this service demands an exceptionally high level of weld integrity, and added to this is the necessity for joining and overlaying unusually thick sections. The shortcomings of existing welding products in meeting the rigid standards set for these applications required the development of a completely new nickel-chromium-iron alloy welding electrode and inert-gas filler wire specifically engineered for nuclear-power-plant fabrication. The covered electrode, designated as MIL Type 4N85, has produced crack-free and porosity-free welds in all positions, even under severely restrained conditions. The increased tolerance of the weld metal for dilution by iron makes this electrode particularly well suited for welding nickel-chromium-iron alloy to carbon or stainless steel and for overlaying steel. The filler wire designated as MIL Type EN87/RN87, intended for welding by the inert-gas-shielded processes, has produced nickel-chromium-iron alloy welds and overlays to the same quality level as the 4N85 covered electrode. The welds deposited by these new materials had good mechanical properties and were not adversely affected by normal stress-relieving heat treatments used for steels.

Introduction

Nuclear power has opened a new field for the 15% chromium, 7% iron, nickel alloy.[1] The excellent resistance of this alloy to stress-corrosion cracking[2,3] has stimulated much interest in its use for the construction of heat exchangers, primary cooling-system piping, reactor-coolant pumps and valves and for cladding of the reactor-vessel interior.[4]

The nature of nuclear-reactor systems requires that welds be essentially free of defects, and added to these demands are the needs for welding unusually heavy sections, sometimes several inches thick. A number of welding electrodes and filler wires that have qualified for years to AWS-ASTM codes have been ruled unsatisfactory for some welding applications in the nuclear-power field, because even the few weld defects which these codes permit could not be tolerated in critical areas. While earlier work indicated that some of the requirements for welding the 15% chromium, 7% iron, nickel alloy for nuclear applications could be met with existing materials,[5] certain objectionable characteristics limited their field of application.

To fill the need for more versatile nickel-chromium-iron welding materials, the MIL Type 4N85 covered electrode and the EN87/RN87 inert-gas filler wire were developed through months of concentrated research effort. Extensive tests and evaluations have shown these materials to be well suited for nuclear fabrication.

The MIL-4N85 Covered Electrode

Description

For critical applications where weld integrity is a prime consideration, the operability of the welding electrode plays an important role and, unquestionably, must be superior in all respects. To insure consistently high-quality welds, arc stability must be excellent and the slag characteristics should provide ease of control of the weld puddle. These are especially important in vertical and overhead welding. The slag also should be friable and readily removable from the completed weld bead. The all-position operation of the 4N85 electrode is excellent, and the slag is easily removed from beads deposited in all positions.

Table 1—All-weld-metal Composition of a MIL-4N85 Electrode Weld Deposit (All Values are Percentages)

Ni	67.0
Cr	14.7
Fe	7.5
Mn	7.7
Cb (+Ta)	2.0
C	0.04
Ti	0.40
Si	0.50
S	0.007
Cu	0.03
Co	0.07

The heavy sections involved in these applications impose high degrees of restraint, generating severe stresses within the weld. For the weld to remain free of cracks under these conditions, the deposited weld metal must be relatively free of impurities which might form weak phases or interdendritic films within the weld structure. The weld metal should also be sufficiently ductile at elevated temperatures. Moreover, in joining nickel-chromium-iron alloy to steel and overlaying steel, the weld deposits must be tolerant of dilution by substantial quantities of iron without detrimental effects.

The 4N85 electrode deposits a nickel-chromium-manganese-iron composition such as shown in Table 1. The electrode is intended for welding the 15% chromium, 7% iron, nickel alloy and making dissimilar welds to materials such as carbon steel and the stainless

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., Apr. 25–29, 1960.

grades, and for overlaying steel.

Weld Tests

Highly - Restrained Butt Welds. Figure 1 shows the joint type used for X-ray evaluation, side-bend tests, and all-weld-metal tensile tests. Joints of 15% chromium, 7% iron, nickel alloy, and dissimilar welds between nickel-chromium-iron alloy and carbon steel were made. After welding, the completed joints were X-rayed, and then sectioned, as shown in Fig. 2. The six $^3/_8$-in. wide transverse slices were used for making 180-deg side bends, and the all-weld-metal tensile specimen was machined from the remaining half of the joint.

Fig. 1—Joint preparation for covered electrode butt-weld test in $1^1/_4$-in. thick plate

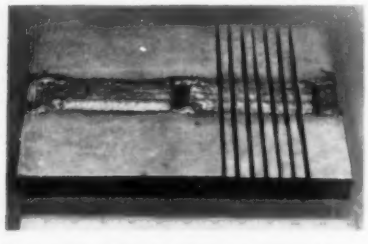

Fig. 2—Covered-electrode butt-weld test joint after sectioning one half for side-bend tests

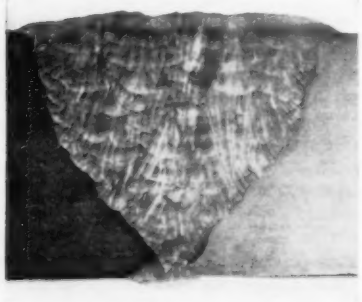

Fig. 3—Cross section of butt weld between $1^1/_4$-in. thick Ni-Cr-Fe alloy and carbon steel welded with MIL-4N85 covered electrode (left member is carbon steel). (About full size)

Figures 3 and 4 show the appearance of a cross section and side-bend specimen, respectively, of a $1^1/_4$-in. thick butt weld in nickel-chromium-iron alloy welded to carbon steel; Fig. 5 and 6 show cross section and side bend of a weld joining 2-in. thick nickel-chromium-iron alloy.

Highly Restrained Overlays on Carbon Steel. It is commonly required in heat-exchanger fabrication to overlay steel tube sheets with weld metal. To assess the quality of an overlay deposit made under highly restrained conditions using 4N85 electrode, a 4-in. thick by 5-in. wide by 10-in. long block of ASTM A-212 pressure-vessel steel, which had been normalized (1650 to 1700° F) and stress relieved (1200–1250° F) was overlayed with three layers of 4N85 weld metal using $^5/_{32}$-in. diam electrodes. The weld beads ran in the 10 in. direction, and each layer contained approximately 25 beads. A preheat and interpass temperature of 300° F was maintained. After overlaying, the block was stress relieved for 9 hr at 1200° F.

To facilitate sectioning and bend testing of side-bend specimens which would reveal the quality of the overlay deposit, the overlayed surface was cut from the major portion of the steel block to provide an overlayed slab of about $1^1/_2$ in. in thickness. Eight $^3/_8$-in. wide longitudinal and 9-transverse slices were then cut from the overlay. The cross sections were polished, etched and examined at ×15 both prior to bending and after making the 180-deg bend. No defects were found in any of the 17 specimens either before or after bending. Figure 7 shows a close-up view of two of the transverse side-bend overlay specimens.

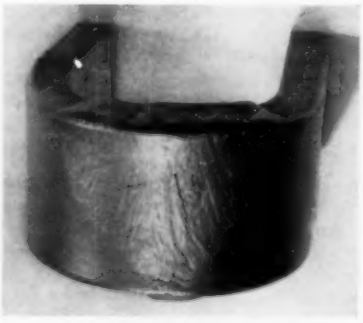

Fig. 4—Side-bend test specimen from butt joint between Ni-Cr-Fe alloy and carbon steel welded with MIL-4N85 covered electrode (left member is carbon steel). (About full size)

A chemical analysis of the overlay deposit revealed 20% of iron at about 0.02 in. from the base metal, and 10% at about $^1/_4$ in. from the base metal.

Fixed - Position Butt Weld in 1-in. Wall. 11-in. OD Ni–Cr–Fe

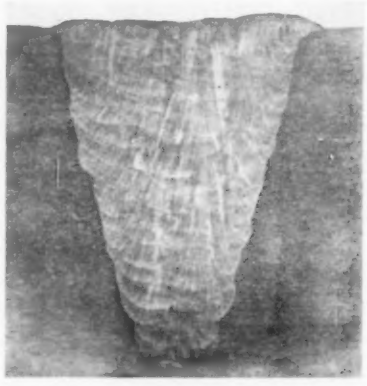

Fig. 5—Cross section of 2-in. thick butt joint of Ni-Cr-Fe alloy welded to Ni-Cr-Fe alloy using MIL-4N85 covered electrode. (About full size)

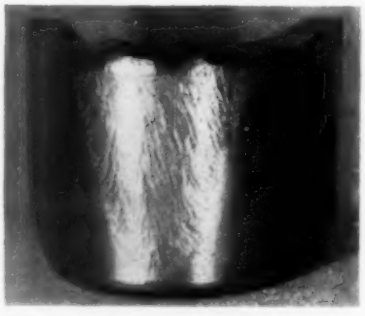

Fig. 6—Side-bend test specimen from butt joint in Ni-Cr-Fe alloy welded to Ni-Cr-Fe alloy using MIL-4N85 covered electrode. (X $^3/_4$)

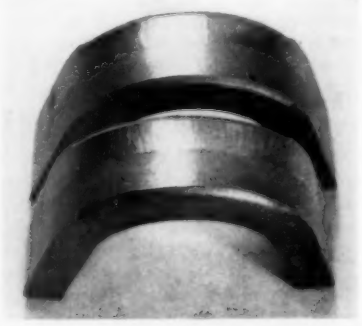

Fig. 7—Side-bend test specimens cut from MIL-4N85 weld overlay on 4-in. thick carbon steel (overlay test block stress relieved before sectioning and bending). (X$^3/_4$)

Alloy Pipe. The butt welding of pipe in a fixed position offers one of the most searching tests for a welding electrode. Deficiencies in the operation or of the slag which might not be apparent in the downhand, or flat, position are clearly evident in the overhead and vertical positions. Also, welds deposited in the overhead position are usually more inclined to be porous. Therefore, since this electrode is intended primarily for use in the fabrication of nuclear-power-plant components, it is essential that the high quality of the deposit be maintained in even the most demanding out-of-position applications.

To demonstrate the performance of the 4N85 electrode under these difficult conditions, a butt joint in 11 in. OD, 1-in. wall, nickel-chromium-iron alloy pipe was prepared. The pipe joint was fixed at about shoulder height with the axis of the pipe horizontal. With the exception of the root pass which was deposited using the inert-gas-shielded tungsten-arc process and a consumable insert ring of MIL-RN6A type alloy, all welding was done with $^1/_8$- and $^3/_{32}$-in. diam 4N85 electrodes without removing or rotating the pipe.

Figure 8 shows the section of pipe containing the butt weld. The welded joint was X-rayed as-welded. The X-ray of the portion of the weld corresponding to a position at about 6:00 to 8:00 o'clock on the joint, as it was positioned during welding, is shown in Fig. 9. Even in this difficult position, the weld was free of porosity.

Properties of MIL-4N85 All-weld Metal

Tensile Strength (Room Temperature). Restrained butt welds of 15% chromium, 7% iron, nickel alloy and joints to carbon steel were prepared using 4N85 electrodes of three different diameters. All-weld-metal tensile specimens were machined from these welds and tested at room temperature. The results of these tensile tests (Table 2) indicate 100% joint efficiency as compared to values for hot-rolled and annealed nickel-chromium-iron alloy plate which has an ultimate tensile strength of 90,500 psi and yield strength at 0.2% offset of 36,500 psi.[6]

Tensile Strength (Short-time High-temperature). Specimens 0.252 in. in diam were machined from the weld metal of $^1/_2$-in thick butt joints of 15% chromium, 7% iron, nickel alloy using $^5/_{32}$-in. diam 4N85 electrodes. These specimens were tensile tested at temperatures ranging from room temperature to 2000° F. The results of these tests are listed in Table 3.

Figure 10 shows the short-time high-temperature tensile strength of the 4N85 weld metal compared to that of hot-rolled and annealed nickel-chromium-iron alloy plate material.[7] The joint efficiency indicated by these tests is over 90% through about 1200° F; above 1200° F, the joint efficiency is 100% with the weld metal being stronger than the plate. The weld-metal ductility does not decrease appreciably until about 1600° F, which is an improvement of about 400° F over nickel-chromium-iron alloy welds made with materials in existence prior to the development of the 4N85 electrode.

Fig. 8—Appearance of fixed-position butt weld in 11-in. OD, 1-in. wall Ni-Cr-Fe alloy pipe, made using MIL-4N85 electrode. (About $^1/_8$ size)

Stress-rupture Properties. Stress-rupture specimens 0.252 in. in diam were machined from butt welds similar to those made for the short-time high-temperature tensile tests. A tabulation of the stress-rupture properties of 4N85 all-weld-metal for 100-, 500-, and 1000-hr life at 1200, 1350, 1600 and 1800° F is given in Table 4. Figure 11 shows a plot of the test data for the 4N85 weld metal compared with that of hot-rolled and annealed nickel-chromium-iron al-

Table 2—Room-temperature Tensile Strength of MIL-4N85 Electrode All-weld-metal Deposits

Test	Electrode type	Plate thickness, in.	Electrode diam, in.	Type of weld[a]	Spec. diam, in.	Ultimate tensile strength, ksi	0.2% yield strength, ksi	Elongation in 1.25 in., %	Reduction of area, %
1	MIL-4N85	$1^1/_4$	$^5/_{32}$	Similar	0.505	92.4	55.1	44.	45.
2	MIL-4N85	$1^1/_4$	$^5/_{32}$	Dissimilar	0.505	92.4	55.1	42.	42.
3	MIL-4N85	$^1/_2$	$^1/_8$	Similar	0.252	95.0	54.8	41.	54.
4	MIL-4N85	$^1/_2$	$^1/_8$	Dissimilar	0.252	92.0	54.2	39.	60.
5	MIL-4N85	$^1/_2$	$^3/_{32}$	Similar	0.252	98.8	61.4	40.	44.
6	MIL-4N85	$^1/_2$	$^3/_{32}$	Dissimilar	0.252	93.6	57.9	38.	50.

[a] Similar = Ni – Cr – Fe to itself; dissimilar = Ni – Cr – Fe to carbon steel.

Table 3—Elevated-temperature Tensile Strength of MIL-4N85 Electrode All-weld-metal Deposits

Test	Electrode type	Test temp., ° F	Ultimate tensile strength, ksi	0.2% yield strength, ksi	Elongation in 1.25 in., %	Reduction of area, %
1[a]	MIL-4N85	600	83.6	46.4	46.	44.
2[a]	MIL-4N85	1100	68.4	41.4	40.	39.
3[a]	MIL-4N85	1600	22.6	20.1	43.	54.
4[a]	MIL-4N85	1800	12.0	11.1	25.	23.
5[b]	MIL-4N85	1900	9.0	7.9	22.	20.
6[b]	MIL-4N85	2000	7.1	6.4	20.	20.

[a] Results are an average of two tests.
[b] Results are for one test only.

Table 4—Stress-rupture Strength of MIL-4N85 All-weld-metal Deposits

Temp., ° F	Stress-rupture life, hr	Stress, psi
1200	100	35,000
1200	500	27,000
1200	1000	24,000
1350	100	14,000
1350	500	11,000
1350	1000	9,500
1600	100	4,700
1600	500	(3,400)[a]
1600	1000	(3,000)[a]
1800	100	1,900
1800	500	(1,300)[a]
1800	1000	(1,100)[a]

[a] Extrapolated

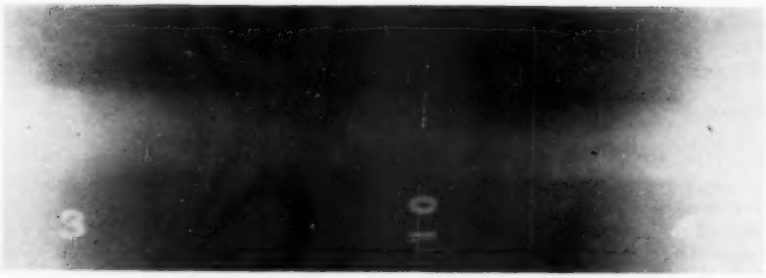

Fig. 9—X-ray of pipe weld shown in Fig. 8 taken at 6:00 to 8:00 o'clock welding position

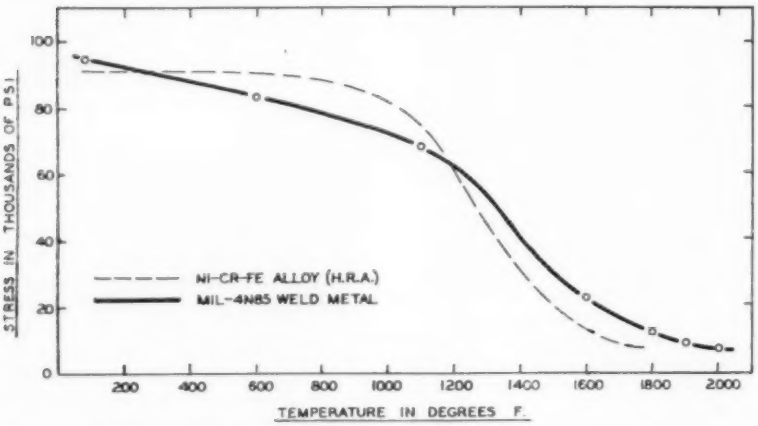

Fig. 10—High-temperature strength of MIL-4N85 weld metal

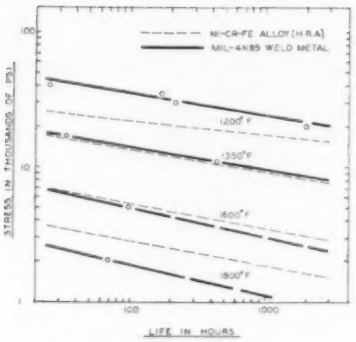

Fig. 11—Stress-rupture strength of MIL-4N85 weld metal

Table 5—Hardness and Impact Strength of As-deposited and Heat-treated MIL-4N85 Weld Metal

Electrode type	MIL-4N85
Electrode diam, in.	5/32
Hardness[a] (Rockwell B) as deposited	92.
Hardness[a] (Rockwell B) after 24 hr at 1300° F	89.
Charpy-V notch-impact strength[a] (ft-lb) as deposited	92.
Charpy-V notch-impact strength[a] (ft-lb) after 24 hr at 1300° F	86.

[a] Average of 6 values.

loy plate.[8] This graph shows that at 1200 and 1350° F, the weld metal is stronger than the plate. At 1600° F, the joint efficiency is 85 to 90%; at 1800° F, the joint efficiency is 60 to 70%.

Effect of Stress - Relieving Heat Treatment on Weld-Metal Properties. Welds involving a carbon or low-alloy steel member or overlays on carbon steel are usually given a stress-relieving heat treatment in the 1050 to 1400° F range with the time at temperature depending on the mass of material. Certain weld-metal constituents, such as titanium, which are added to welding electrodes and filler wire for deoxidation purposes, may cause a precipitation - hardening of the weld deposit within the 1050–1400° F stress-relieving range if these elements are present in sufficient quantities. This hardening effect may consequently impair the ductility and notch toughness of the weld metal.

It is essential, therefore, that the composition of the weld deposit be carefully controlled to avoid this occurrence. The 4N85 electrode provides the necessary deoxidation, yet the residual deoxidant level is low enough to avoid precipitation-hardening during the normal stress-relieving heat treatments for steels to which the weld may be exposed.

Table 5 shows the hardness and impact strength of 4N85 weld metal in both the as-welded and stress-relieved conditions. There was no significant change in hardness or impact strength of the weld metal after being subjected to stress-relieving temperatures for extended periods of time.

MIL-EN87/RN87 Inert-gas-shielded Filler Wire

Description

The EN87/RN87 inert-gas-shielded filler wire is a companion product to the 4N85 covered electrode intended for gas metal-arc (EN87) and gas tungsten-arc (RN-87) welding, and was designed primarily for fabricating nickel-chromium-iron alloy components for nuclear-power plants.

This filler wire deposits non age-hardenable welds and overlays and is suitable for making dissimilar welds between 15% chromium, 7% iron, nickel alloy and carbon or stainless steels. The chemical composition of a EN87/RN87 filler wire is shown in Table 6.

Table 6—Composition of a MIL-EN87/RN87 Filler Wire (All Values Are Percentages)

Ni	72.
Cr	20.
Fe	1.0
Mn	3.0
Cb (+Ta)	2.6
C	0.03
Ti	0.30
Si	0.30
S	0.009
Cu	0.02
Co	0.04

Weld Tests

Highly Restrained Butt Welds. Welds 1 in. thick of nickel-chromium-iron alloy and dissimilar joints between nickel-chromium-iron alloy and carbon steel were prepared for X-ray, side-bend tests and all-weld-metal tensile tests. Restraint during welding was provided by clamping the joint members to a 6-in. thick steel platen. This paper will deal only with welds made using the 0.062-in. diam EN87 wire and the manually controlled gas metal-arc process since experience has indicated gas metal-arc to be more demanding than the tungsten-arc process. Welding

current was adjusted to provide a spray-type transfer. Most welds were made at about 280 amp and 27 v DCRP with pure-argon shielding. A completed butt weld is shown in Fig. 12.

Figure 13 shows a side-bend specimen from a nickel-chromium-iron alloy weld; Fig. 14 shows a side bend specimen from the weld joining nickel-chromium-iron alloy to carbon steel.

Highly Restrained Overlays on Carbon Steel. Overlays consisting of three layers of nickel-chromium-iron weld metal were deposited using the gas metal-arc process automatically controlled and 0.062-in. diam EN87 filler wire. The completed overlayed blocks were stress relieved, processed for evaluation and tested in the same manner as the covered-electrode overlays described earlier. Figure 15 shows the appearance of three side-bend test specimens from an EN87 overlay made by the gas metal-arc process.

Table 7 is a list of results of hardness impressions taken across a cross section of the overlay deposit both before and after stress relieving for 9 hr at 1200° F. No hardening occurred during the heat treatment.

Simulated Tube to Tube-Sheet Welds. A large percentage of the overlaying of carbon steel with nickel-chromium-iron alloy for nuclear applications will be for heat-exchanger applications in overlaying tube sheets. Since the heat exchanger tubing is usually welded to the tube sheet with the weld being between the overlay deposit and the tube, it was necessary to determine if satisfactory joints could be made between nickel-chromium-iron overlays of EN87 and nickel-chromium-iron alloy tubes.

Perhaps the most demanding type of weld joining a tube to a tube sheet is a simple fusion of the two without the addition of filler material. Therefore, to test the feasibility of this kind of weld, a block of ASTM A-212 pressure-vessel steel overlayed with a 3/8-in. deposit of EN87 weld metal and stress relieved 9 hr at 1200° F was prepared for making a series of such welds. The top surface of the overlay was ground to a smooth finish and bored with 1/2 in. diam holes spaced 3/4 in. apart, center-to-center, in a staggered pattern simulating a typical tube-sheet configuration.

About 50 holes were prepared, degreased and fitted with 1/2 in. OD, 1/16-in. wall nickel-chromium-iron alloy tubes, the tube positioned with its end flush with the top surface of the overlayed "tube sheet." The tube ends were expanded against the tube wall with a tapered drift punch to provide a snug fit. The tubes were then welded in without the addition of filler metal using the gas tungsten-arc process under the conditions listed in Table 8.

Figure 16 shows the surface appearance of one of the tube to tube-sheet welds; Fig. 17 is a photomicrograph of a longitudinal cross section cut parallel to the tube axis. No porosity or cracking was observed in any of the cross sections.

Table 7—Hardness Traverse of MIL-EN87 Ni – Cr – Fe Overlay Cross Section (Rockwell B)[b]

Condition of overlay	Location of hardness impressions: 1/16 in. below overlay surface	1/8 in. below overlay surface	3/16 in. below overlay surface	1/4 in. below overlay surface
As-welded	87.	86.	88.	88.
S.R.[a]	88.	87.	88.	88.

Condition of overlay	[b]1/16 in. below overlay surface	Near overlay interface	1/16 in. below interface (in steel)	1/8 in. below interface (in steel)
As-welded	88.	88.	84.	84.
S.R.[a]	88.	83.	80.	75.

[a] 9 hr at 1200° F.
[b] Average of 3 impressions.

Fig. 12—Completed 1-in. thick butt joint in Ni-Cr-Fe alloy welded using MIL-EN87 filler wire and gas-metal-arc process

Fig. 13—Side-bend test specimen cut from 1-in. thick butt joint of Ni-Cr-Fe alloy welded to Ni-Cr-Fe using MIL-EN87 filler wire. (About full size)

Tensile Properties of MIL-EN87 All-weld Metal

As previously indicated, highly restrained single U-groove butt

Table 8—Welding Conditions for Simulated Tube to Tube-sheet Welds

Welded semiautomatically by gas tungsten-arc process; torch fixed, tube-sheet rotated; torch axis inclined 70 deg toward tube axis (from horizontal)
Peripheral welding speed: about 14 ipm
Arc length: 0.050 in.
3/32-in. diam tungsten electrode extended 1/4 in. beyond nozzle
Gas cup diameter: 3/8 in.
Argon shielding gas: flow rate 20 cfh
Welding current: 170 amp, DCSP
Welding volts: 12 v, DCSP

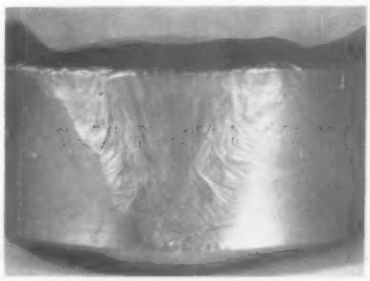

Fig. 14—Side-bend test specimen cut from 1-in. thick butt joint between Ni-Cr-Fe alloy and carbon steel welded with MIL-EN87 filler wire (left member is carbon steel). (About full size)

Fig. 15—Overlay side-bend test specimens cut from MIL-EN87 overlay on 4-in. thick carbon steel (overlay test block stress relieved before sectioning and bending). (About 3/4 size)

Table 9—Room-temperature Tensile Strength of MIL-EN87 All-weld-metal Deposits

Test	Filler wire type	Filler wire diam, in.	Type of weld[a]	Spec. diam, in.
1	MIL-EN87	0.062	Similar	0.505
2	MIL-EN87	0.062	Dissimilar	0.505

Test	U.T.S. ksi	0.2% yield strength ksi	Elongation in 1.25 in. %	Reduction of area, %
1	96.2	57.1	45.	56.
2	94.5	57.0	41.	52.

[a] Similar = Ni – Cr – Fe to itself; dissimilar Ni – Cr – Fe to carbon steel.

welds 1 in. thick were prepared using 15% chromium, 7% iron, nickel alloy for both sides of the joint, and dissimilar welds were also prepared between nickel-chromium-iron alloy and carbon steel. Tensile specimens 0.505 in. in diam for tests at room temperature were machined from the weld metal of these butt welds; the results are shown in Table 9. These values indicate 100% joint efficiency as compared to the tensile strength of hot-rolled and annealed nickel-chromium-iron plate.[9]

Compatibility of MIL-EN87 with Other Ni-Cr-Fe Welding Materials

The situation might arise where it will be necessary to deposit the EN87/RN87 filler in conjunction with other types of 15% chromium, 7% iron, nickel-alloy welding materials. A brief study was made to determine whether dilution of these materials with deposits of other types of nickel-chromium-iron covered electrodes and filler wires would have any adverse effect on weld quality.

Three materials were selected as being most likely to be encountered during fabrication. These were covered-electrode types 3N12 and 4N85 of MIL-E-17496(SHIPS), and filler-wire type EN62 of MIL-E-21562(SHIPS). A restrained overlay was prepared wherein the 3N12, 4N85 and EN62 materials were deposited, side by side, on top of a deposit of EN87; another specimen, similar to this but having the EN87 on top of the 3N12, 4N85 and EN62 deposits, was also prepared. These overlays were deposited on 4-in. thick pressure - vessel steel to provide conditions of high restraint. After overlaying, the specimens were stress relieved for 9 hr at 1200° F, cross sectioned and given side-bend tests. The absence of cracking at or near the interface of the various overlays with EN87 indicated that this new filler is inherently compatible with other nickel-chromium-iron weld metals, even under conditions of high restraint.

Fig. 16—Surface appearance of tube to tube-sheet weld between MIL-EN87 overlay deposit on carbon steel and Ni-Cr-Fe tube using the gas tungsten-arc process (no filler added). (About 1¼ size)

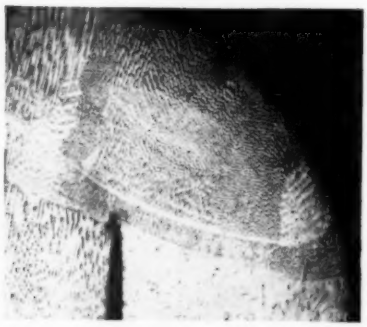

Fig. 17—Cross section of tube to tube-sheet weld cut parallel to tube axis. X 45. (Reduced by ½ upon reproduction)

Conclusions

1. The MIL-4N85 type covered welding electrode has produced crack-free and porosity-free welds in all positions and under high restraint in the 15% chromium, 7% iron, nickel alloy, and between nickel-chromium-iron alloy and carbon steel.

2. Overlays on carbon steel and dissimilar joints between nickel-chromium-iron alloy and carbon steel made using the MIL-4N85 type covered electrode have been subjected to the normal stress relieving temperatures used for steels without any adverse effect on the weld-metal properties.

3. The MIL - 4N85 type covered electrode has deposited weld metal having good physical properties with joint efficiencies of over 90% in short-time tensile tests from room temperature through 2000° F, and stress - rupture joint efficiency of 100% through 1350°F.

4. The MIL - EN87/RN87 type filler wire for inert-gas-shielded welding has produced crack-free and porosity-free welds under conditions of high restraint in the 15% chromium, 7% iron, nickel alloy and between nickel-chromium-iron alloy and carbon steel, and is well suited for overlaying carbon steel in heavy sections.

5. Carbon-steel overlays and dissimilar joints between nickel-chromium-iron alloy and carbon steel made using MIL-EN87 type filler wire have also been subjected to the normal stress-relieving temperatures used for steels without any adverse effect on the weld-metal properties.

6. Tube to tube-sheet welds, free of cracking and porosity, have been made successfully between EN87 overlays and nickel chromium-iron alloy tubes with the gas tungsten-arc process without the addition of filler metal.

7. The MIL-4N85 and MIL-EN87 types of welding materials have been welded into deposits of other types of nickel-chromium-iron covered electrodes and filler wires, such as the 3N12 electrode and EN62 filler wire without adverse effect on weld quality.

Acknowledgment

The author expresses his appreciation to The International Nickel Co., Inc., for making this publication possible.

References

1. *Engineering Properties of Inconel*, Techn. Bull. T-7, Huntington Alloy Products Division, The International Nickel Co., Inc., New York (Sept. 1959).
2. Copson, H. R., and Berry, W. E., "Qualification of Inconel for Nuclear Power Plant Applications," *Corrosion*, **16**, No. 2, 79t–85t (Feb. 1960).
3. Friend, W. Z., "Corrosion Problems in Nuclear Reactor Power Stations," *Proc. Am. Power Conf.*, **XVIII** (1956).
4. Cordovi, M. A., "Qualification of Inconel Ni-Cr Alloy for Nuclear Power Plant Applications," Status Rept. No. 3, The International Nickel Co., Inc., New York (Jan. 1960).
5. Fragetta, W. A., and Pense, G. R., "The Welding of Inconel for Nuclear Power Application," THE WELDING JOURNAL, **38** (4), 347–356 (1959).
6. "Engineering Properties of Inconel," *op. cit.*, p. 8.
7. *Ibid.*
8. *Ibid.*
9. *Ibid.*

Fabrication Principles for Welded Inconel X Structures

Test program results in the establishment of procedures required for the fabrication by welding of large-size pressure vessels from age-hardened nickel-base alloys

BY H. P. SCHANE AND E. E. WEISMANTEL

SUMMARY. The designing of structures of most nickel-base precipitation hardening alloys is critical for service applications in the low-ductility range of 1150 to 1350° F which also corresponds to the aging temperature.

This paper describes the manufacturing techniques that affect the design and serviceability of critical units. It discusses, in detail, various joint designs and the effect of these designs on weld-joint efficiency. It also stresses weld-cleaning requirements and the effect of improper cleaning on weld quality. Special welder-qualifying procedures are outlined to determine the ability of producing consistent high-quality welds for service at elevated temperatures. The necessity for post-welding stress relief and final heat treatment is discussed as these operations affect the serviceability of the unit.

Introduction

In the past several years, there has been an increased need for pressure vessels which operate reliably under relatively high stress levels at temperatures above 1000° F. This has been particularly true where such vessel applications require that weight be held to a minimum.

Four years ago, the Budd Co. received a design contract to develop a large welded pressure vessel to very limiting weight requirements. This paper describes the fabrication conditions and other factors that were found necessary for the engineering development of this first unit and for a subsequent unit which would be exposed to operating conditions that were even more demanding than those encountered in the first assembly.

Normal pressure-vessel materials such as the austenitic stainless steels used for immobile units require such low operating stresses that a power plant designed of these materials would be prohibitively heavy. Many higher-strength alloys have been developed which could be considered, but for the product we were designing, and after thorough consideration of all available alloys, Inconel X was felt to be most suitable. Since the late 1940's, when it first became widely accepted as a material for elevated-temperature service, this alloy had been found to be relatively more reliable and more fabricable than other competitive alloys which could operate under the same design conditions. Previously, a pressure vessel had not been made which would operate under the required conditions. This alloy was selected because of proved reliability to operate at high stress levels between 1000 and 1300° F and the proved ability to fabricate heat-treated welded structures of this alloy. The designing of structures of most nickel-base precipitation-hardening alloys is critical for service applications in the low ductility range 1150–1350° F which also corresponds to aging temperature. The use of welded structures in this range makes the recognition of additional fabricability factors of prime importance beyond the principles observed for nonwelded assemblies, or for assemblies made of nonaging materials.

From the fabricability standpoint, the initial problem was to determine the best welding process which would consistently produce the highest-strength welds to meet the design requirements. Available data were reviewed and definitely indicated the advantages of the inert-gas-shielded tungsten-arc process, where weld-metal deposits could attain an ultimate tensile strength of 92 to 93% of the base metal after heat treatment. In contrast, when welding this metal using a covered electrode, weld-metal deposits might only attain strengths of approximately 60% of the base metal. This difference would become even more accentuated at the design temperature. Based on this information, the tungsten-electrode inert-gas-shielded arc process was chosen for all subsequent work.

Since the operation of the pressure vessel would subject the weld joints to fatigue, thermal shock and high steady-state stresses, all weld joints were designed for butt welding. Evaluation of these welds included the creep-rupture testing of specimens cut from these test welds.

The final design of the pressure vessel required that practically all of the butt welds must be welded from one side and meet the following standards:

1. Welds must have 100% penetration with uniform reinforcement at both root and face.
2. No sharp contours simulating a notch effect would be acceptable at the face or root of the welds.
3. Welds must be made with a minimum of heat input to minimize shrinkage and distortion.
4. No cracking or elongated voids would be acceptable.
5. Where possible, all weld edges must be butted together with no gap, to minimize shrinkage. This would also produce more consistent welding conditions necessary for consistent weld penetration.

Prior to the development of the final weld-joint design, many tests were made using the conventional joint preparation of the single vee and U-joints (Fig. 1). Welds were

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Table 1—Initial Experimental Weld Data

Tentative Weld Procedure:
- Welding process—Inert-gas-shielded tungsten-arc process
- Welding characteristics—Direct current, straight polarity
- Weld current—100 to 200 amp
- Weld voltage—20 v
- Gas at torch—Helium, 20 cfh
- Backing gas—Argon, 10 cfh
- Electrode—$^{3}/_{32}$ tungsten
- Filler rod—$^{1}/_{16}$ AWS ERN69

Note: (1) Use no filler rod on root pass. (2) Clean each pass by aluminum oxide blasting and stainless steel wire brushing prior to subsequent weld passes.

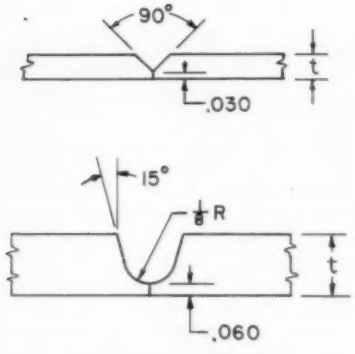


Fig. 1—Conventional design of weld joints used for preliminary weld tests

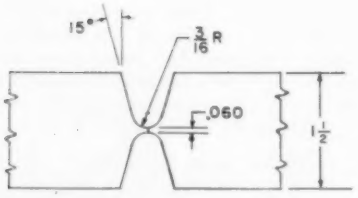


Fig. 2—Double "U" weld-joint preparation for preliminary weld-deposition experiments

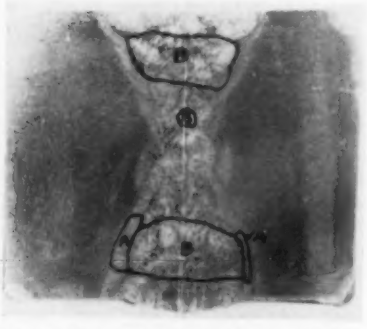


Fig. 3—Macrograph of weld deposit of multiple-pass weld showing areas of fissuring defects

also made on straight abutted edges to determine the necessity of edge preparation.

During these tests, it was determined that consistently sound root passes could be obtained without the use of filler-metal additions, the base metal having a balanced enough alloy content to avoid cracking during solidification. Thus to avoid another variable which would affect distortion shrinkage and penetration, all subsequent welding was scheduled to use no filler-wire additions for root pass welds. The filler metal used for cover passes met AWS specification ERN69. These tests and all subsequent tests were made using an Inconel X backing in which a $^{1}/_{2}$-in. wide by $^{1}/_{8}$-in. depth groove had been machined to permit inert-gas backing. The inert backing gas was found necessary to avoid oxide formation and to obtain the proper wetting action for procurement of a uniformly contoured weld root.

Development of Weld-joint Design

After initial welding tests, it was found necessary to further modify the joint design and welding techniques to develop the optimum weld for the various gages to be used.

The first requirement was to develop the welding technique for producing a consistently sound weld. Double-U joints were prepared in $1^{1}/_{2}$-in. thick plates (see Fig. 2), and a tentative welding procedure established. Interpass weld cleaning was rigidly stressed, as it was known that the oxide formed from the previous weld pass was of a higher melting temperature than the base metal and thus might not be remelted by the subsequent pass, causing porosity or stringers. Aluminum-oxide blasting was used for this cleaning operation followed by manual stainless-steel wire brushing. The tentative welding procedure is shown in Table 1.

Figure 2 shows the weld-joint preparation and Fig. 3 a photomacrograph of a cross section of this test weld. As will be noted no difficulty was encountered at the weld root but throughout the balance of the weld deposit, microcracks and fissures occurred but in no definite pattern or direction. Almost all of these defects occurred after the specimen was highly restricted by the previous weld deposits. During this test, the specimen had been allowed to air cool below 200° F before each subsequent pass. A total of 48 weld passes was required. After examination, it was decided that most of these defects were at the interface between weld beads and in areas where weld beads were deposited at high weld currents. The use of low welding currents, narrow weld passes and positive removal of surface oxide would have definitely minimized these defects. All future weld tests were made using welding currents varying from 110 to 140 amp and narrow stringer passes. These difficulties were not a major problem in the subsequent work.

Development of Final Weld-joint Preparation

Several types of edge preparations were used on subsequent weld-test specimens to eliminate the occasional back melting at the weld root. These are shown in Fig. 4.

Best results were obtained using the design shown in Fig. 5, but consistent uniform weld roots were not obtained until the torch angle was set at 20 deg and directed so that it favored one plate only. The swirling action of the weld puddle washing into the joint between the two plates produced a uniform root penetration.

Figure 6 shows results of back melt when torch was directly verti-

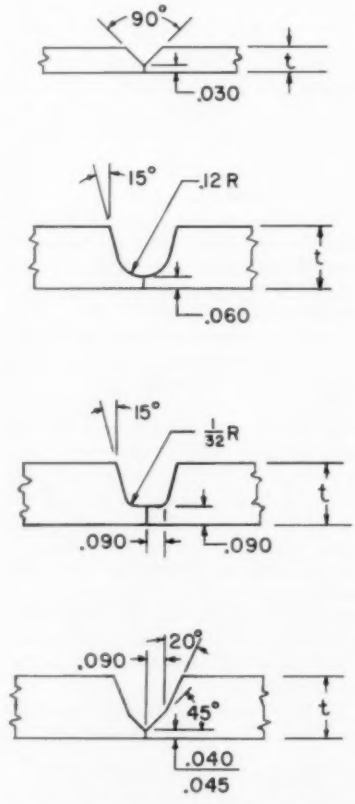


Fig. 4—Butt-weld joint designs used in experimental weld tests

cal to the weld joint. The macrograph at the right shows the uniform root reinforcement obtained by angling the torch 20 deg. This figure also shows the segregation of heavy and partially dendritic grains in the macrograph at left which is undesirable. The grain structure of the bottom macrograph is more uniform and lacks the coarse dendritic structure. Subsequent creep-rupture tests at high temperature verified that a fine equiaxed grain structure increased the test life of the weld and that premature rupture failure was associated with the dendritic grain structure illustrated.

Figure 7 shows the weld-root appearance for welds made using three different techniques. Close examination indicates that a uniform condition with respect to fall through or back melt is definitely a function of the welding technique.

Many other weld-joint types, such as corner joints and tee joints, were made. Since these joints would of necessity be welded from one side and samples made did not assure the production of uniform radius contoured weld roots, these type joints were eliminated from the final product design.

The final joint designs for fabrication are shown in Fig. 8. For metal thicknesses up to $^1/_2$ in., design A applies. For metal thicknesses over $^1/_2$ in., design B applies. For metal thicknesses where welding could be performed from both sides, alternately, design B and design C apply.

The welding procedure was the same with the exception that where welding from both sides and back melt of the weld root was advantageous from a standpoint of weld cleaning, the electrode was directed vertically into the abutted joint.

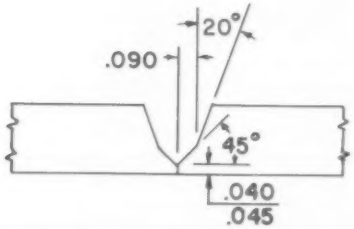


Fig. 5—Optimum joint design when welding from one side only

Qualification of Welding Operators

During this program, it was found that standard physical testing and X-ray inspection is insufficient to determine the ability of the welder to produce high-quality welded joints for service at elevated temperatures. Welds tested by these methods were subjected to creep-rupture tests at elevated temperatures with inconsistent results.

Investigation of these creep-rupture test specimens revealed that the early failure of some of these specimens was due to the following:

1. Very fine microcracks.
2. Interface lack of fusion due to insufficient cleaning.
3. Large dendritic grains.

Review of X-rays revealed that it was impossible to locate and interpret these minor defects. Moreover, the grain structure was purely a function of welder technique.

It was decided that the standard testing of welder-qualification specimens be supplemented with the creep-rupture test of heat-treated weld joints. This test was to be conducted at the maximum temperature specified for operation of the pressure vessel being designed. To shorten the test time, the welds in the heat-treated specimens were stressed to 75,000 psi at 1200° F. Welds which contained objectionable defects failed upon loading or shortly thereafter, whereas satisfactory welds did not break in less than five hours.

The use of welders so qualified still does not provide certainty of optimum welding results unless the supervision and inspection personnel are aware of the necessity for thorough cleaning and exacting fit-up requirements. In addition, all surface imperfections of previous weld passes, regardless of size, must be completely removed before further welding.

Defects Relative to Failure

A review of the results of all weld-procedure test specimens showed that the failures were related to the specified weld defects, weld face, contour, or root contour.

Figure 9 shows etched cross sections of welded joints that would be

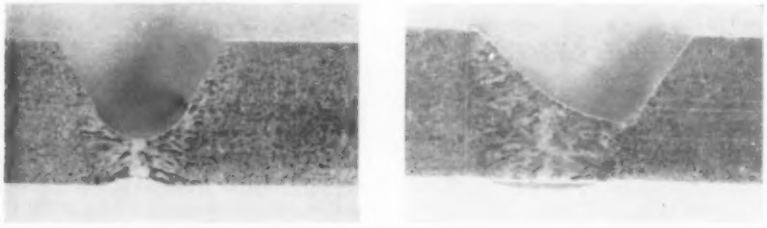


Fig. 6—(left) Macrograph showing back-melt and heavy dendritic weld structure when torch was held vertical; (right) macrograph showing uniform penetration and more uniform grain structure when torch was angled at 20 deg from vertical

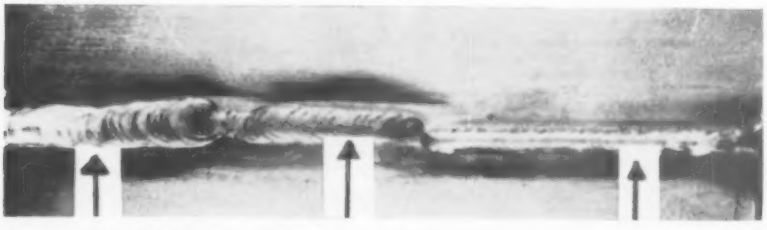


Fig. 7—Photograph of weld root showing the effect of welding technique on shape of root contour

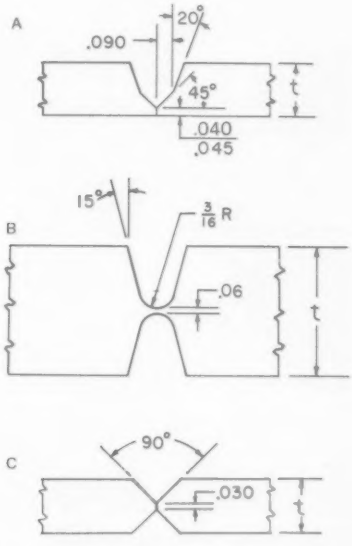
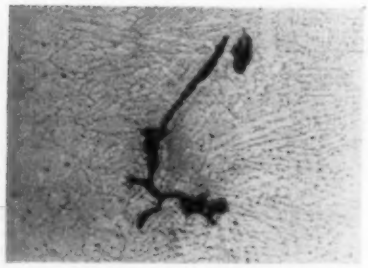
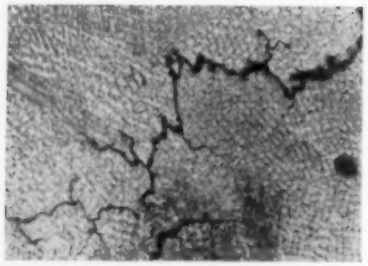


Fig. 8—Weld-joint edge preparation for use on final design drawings

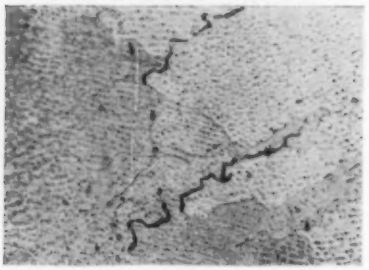
Fig. 9—Macrographs of weld showing defects that cause premature failure at elevated operating conditions



Micrograph of oxide inclusion.



Micrograph of segregation and hot-tear cracking. Typical weld metal cracking in end of $1^1/_2$-in. plate weld



Micrograph of hot-tear cracks on grain boundaries. Typical weld metal cracking in end of $1^1/_2$-in. plate weld

Fig. 10—Photomicrographs of Inconel X weld deposits showing typical weld defects. Etchant: Marble's reagent. × 100. (Reduced by one-half upon reproduction)

subject to premature failure at elevated-temperature operating conditions.

Figure 10 shows micrographs of typical defects created by improper cleaning and/or excessive restraint. Notice that the fissuring of the weld is predominately in the grain boundaries characteristic of hot tears formed during final solidification of the weld metal.

Heat Treatment of Inconel X

Two standard heat treatments are recommended for use on this material, the selection to be dependent upon the service temperature of the structure. If the service temperature is not expected to be above 1100° F, the recommended practice is to procure the material in the mill-annealed condition (1900–1950° F) after which strengthening is accomplished by a single aging treatment of 20 hr at 1300° F. For applications above this range a solution treatment is required followed by a double aging treatment of 24 hr at 1550° F and 20 hr at 1300° F.

These heat treatments are adequate for structures which are not fabricated weldments. If these materials are to be used in welded structures, other factors must be considered which make the desired heat-treatment conditions difficult to achieve.

Residual welding stresses combined with a low-ductility range, 1100 to 1350° F, demand that this material not be placed in service nor heat treated in this temperature range immediately after welding.

It is important that all weldments in this type of alloy be stress relieved before final aging. To accomplish maximum stress relief, the temperature should be as high as possible (up to the mill-annealing or solution-annealing temperatures, as required). However, dimensional tolerances, oxidation, furnace limitations, etc., favor using as low a stress-relieving temperature as is practical. Experience has shown that 1625° F is the lowest temperature recommended for this operation. This treatment must be applied with special care to insure rapid heating of the weldment to avoid dwelling for too great a time in the low-ductility range during the initial heating. Thus it is common practice to charge the unit into an overheated furnace to obtain highest possible heating rates.

Since stress relief is required after welding and before aging, it may be impractical to achieve the standard heat-treat conditions recommended for the alloy. A complicating factor is the lack of design data which considers the effect of such an intermediate heat treatment on either the base metal or on the weld metal

Early in this program it was necessary to begin a thorough evaluation of the effect of these changes in heat-treating schedule on the creep-rupture and tensile performance of the material. Figure 11 shows typical design curves that were developed for the base metal and the weld metal under these conditions. In addition, statistical study which compared the usage of a 4 hr 1625° F stress relief and the 1300° F age with the 24 hr 1500° F treatment followed by the 1300° F age showed no great preference for either treatment. Therefore, the standard processing for this unit became:

	Service below 1100° F	Service above 1100° F
Initial material condition	1900° F (mill anneal)	2100° F (solution anneal)
Fabricate and weld	...	...
1625° F	4 hr	4 hr
1300° F	20 hr	20 hr

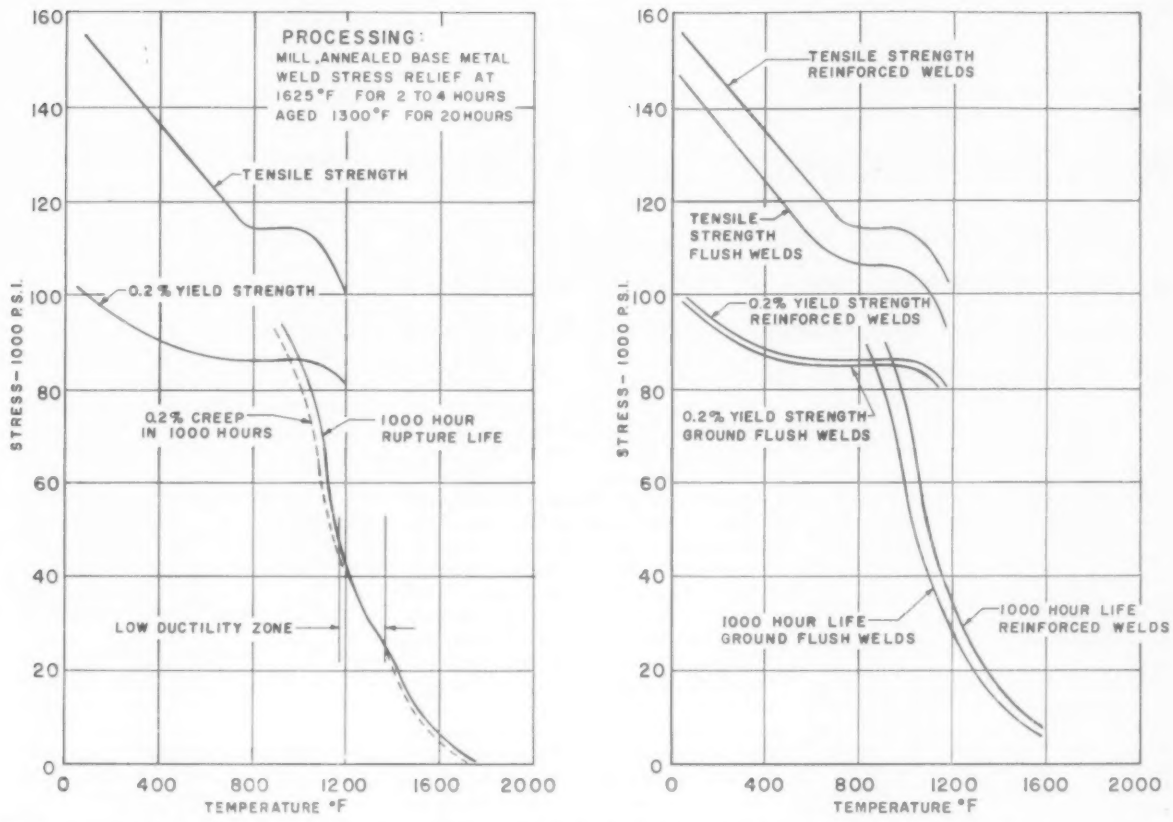

PROCESSING:
MILL ANNEALED BASE METAL
WELD STRESS RELIEF AT
1625°F FOR 2 TO 4 HOURS
AGED 1300°F FOR 20 HOURS
TENSILE STRENGTH
0.2 % YIELD STRENGTH
0.2% CREEP IN 1000 HOURS
1000 HOUR RUPTURE LIFE
LOW DUCTILITY ZONE
STRESS - 1000 P.S.I.
TEMPERATURE °F
TENSILE STRENGTH REINFORCED WELDS
TENSILE STRENGTH FLUSH WELDS
0.2% YIELD STRENGTH REINFORCED WELDS
0.2% YIELD STRENGTH GROUND FLUSH WELDS
1000 HOUR LIFE GROUND FLUSH WELDS
1000 HOUR LIFE REINFORCED WELDS

Fig. 11—Inconel X—minimum predicted performance values for heat-treated base metal (left) and weld metal (right)

Conclusions

1. This program has resulted in the establishment of the procedures required for the fabrication by welding of large-size structures from age-hardened nickel-base alloys.

2. The procedures that were chosen are consistent with other weld procedures previously found necessary for fabrications made from these materials.

3. This processing requires a heat-treating sequence which differs from the standard strengthening treatments for the unwelded alloys.

4. Design data were obtained for the modified heat-treat sequence for both the base metal and fusion-welded joints.

5. No major cracking problems were encountered in the heat treating of highly restrained weldments, other than those which were associated with weld defects that were present before heat treatment.

6. Oxides, microcracking and severely dendritic structures were found to have a major effect on rupture life, and welding techniques were modified to hold their occurrence within controllable limits.

7. It was found that welder-qualification tests should include some testing at elevated temperatures to evaluate fully the welding techniques on these materials.

Acknowledgment

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Welding of High-Strength Steels for Rocket Cases

Investigation indicates that low-carbon filler and grain refinement improve notch properties and, under the most severe conditions of stress concentration and temperature, result in the best combination of notch strength and ductility

BY W. H. KEARNS, J. W. SEMMEL AND J. D. MARBLE

ABSTRACT. The utilization of ultra-high-strength low-alloy steels for solid-propellant rocket cases requires consideration of their weldability. Steels of this type contain 0.40% carbon or more which necessitates special welding techniques to produce sound welds with adequate ductility, strength and notch toughness.

A study of the weldability of three typical high-strength steels—300M, X-200 and D6A—was made. Procedures were developed for making sound weldments in the three steels by the inert-gas-shielded tungsten-arc welding process. Preheating and post-heating procedures were established. A special ceramic backing bar was developed to avoid weld cracking.

Filler-wire compositions and heat treatments for the three steels were evaluated by mechanical property tests and metallographic studies. A special heat treatment was developed to reduce the prior austenitic grain size in the welds. Improved weld-joint ductility and notched toughness were obtained, using low-carbon filler wires and/or the grain-refining heat treatment. For the most severe service conditions, both low-carbon filler wire and grain refinement are recommended.

Introduction

Solid-propellant intercontinental ballistic missiles require rocket cases of high strength-to-weight materials to improve performance by minimizing the case-weight to total weight ratio. Ultra-high-strength steels that can be heat treated to yield strengths of 230,000 psi and higher are applicable, and there are several new low-alloy steels which are being used or considered for missile cases. These are of the AISI 4340 type of steel with modifications in chemistry to increase hardenability and strength. During the firing of the missile, the cases are subjected to high internal gas pressures which result in biaxial stresses.

For this application, one of the prime considerations in the selection of a steel for cases is its weldability. The cases contain a cylindrical section which may or may not have a longitudinal seam. Forward and aft domes are joined to the cylinder by arc welding. Therefore, the welded joints must be designed to carry the stresses which the case will experience in service.

This paper describes the evaluation of welding procedures, heat treatments and filler wires for three commercial low-alloy high-strength steels for potential rocket-case applications. Procedures were developed for producing sound butt welds by the inert-gas-shielded tungsten-arc process. Filler wires of base-metal composition and modified compositions were evaluated for producing strong, ductile welds in the alloy steels. A detailed study of heat-treating procedures on one alloy resulted in a heat treatment that refined the prior austenite grain size in the weld- and heat-affected zones. Both the grain-refining heat treatment and the standard heat treatment were evaluated for all three alloy steels. The strength and ductility of weldments were measured by tensile tests, notched tensile tests and bend tests.

Welding Metallurgy

Ultra-high-strength steels capable of being heat treated to 230,000 psi yield strength contain about 0.40% carbon for hardenability and strength. Alloy additions in the steels make them air hardenable in sections 1 to 2 in. thick by suppressing the transformation of austenite to pearlite and bainite. The resulting structure of the steels after heat treatment is tempered martensite. A typical isothermal transformation diagram for a steel of this class is illustrated in Fig. 1.

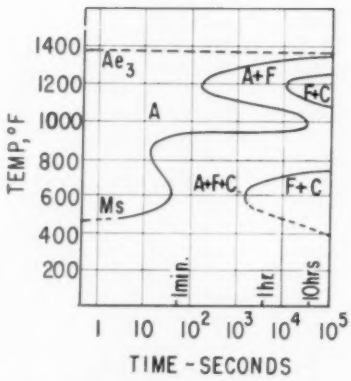

Fig. 1—Isothermal-transformation diagram for 4340 steel

The steels generally contain two or more of the elements chromium, nickel, molybdenum and vanadium. Some steels contain between 1.5 and 2% silicon to retard the softening in the 400 to 600° F tempering range.[1] Silicon additions also raise the tempering temperature at which the notch-impact energy decreases (temper-brittleness range).[2]

The hardness, strength, notch properties and ductility of the low-alloy steels are related to alloy composition and heat treatment. The steels are transformed to martensite by rapid air cooling from the austenitic region. Subsequent tempering decreases the hardness and tensile strength, and improves ductility without a significant decrease in yield strength. The uniaxial tensile properties of three typical steels after double tempering at various temperatures are shown in Fig. 2.

The ultimate and yield strengths of the steels decrease with increas-

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Table 1—Chemical Composition of the High-strength Steels

Alloy	Heat no.	Thick-ness, in.	C	Mn	Si	Ni	Cr	Mo	V	P	S	Other
300M	K-3266	0.080	0.41	0.85	1.75	1.88	0.78	0.31	0.14	0.012	0.005	0.08 Al
X-200	X-38832	0.093	0.41	0.84	1.51	0.10	1.83	0.36	0.07	0.013	0.015	0.09 Cu
D6A	D-16370	0.093	0.43	0.82	0.31	0.47	1.02	1.05	...	<0.03	0.016	0.06 Al

ing tempering temperatures. At the same time ductility is improved. At high-strength levels, the notched-tensile strength may be below the unnotched strength depending on the composition. At higher temperatures, the notched-tensile strength increases until it exceeds the unnotched strength. The notch sensitivity of an alloy is important in predicting its behavior under stress concentrations in a structure.

Considerable knowledge is available on the welding of the 4300 series of steels. They have been welded by covered electrode metal-arc and inert-gas processes. The weldments must be heat treated to obtain the desired mechanical properties. The cast weld metal has a different metallurgical structure than the base metal, and it may be stronger, less ductile and more notch sensitive than the base metal. Welds in steels, such as AISI 4340, heat treated to above 200,000 psi yield strength, may have low ductility and low resistance to crack propagation. These factors have limited the applications of steels heat treated to above 200,000 psi yield strength in aircraft and missile structures because of the danger of premature failures at average stresses below 200,000 psi.

The ductility of arc welds in low-alloy high-strength steels can be improved by modifying weld filler-wire composition and by heat treatment. Reducing the carbon content of the filler wire has the greatest effect on lowering the hardness and increasing ductility. Other modifications in alloy content can also be made to improve weldability. For example, AISI Type 502 filler wire (0.10% max. C, 1.0% max. Mn, 1.0% max. Si, 4–6% Cr) has been used to weld AISI 4335 steel. Type 17-22 AS filler wire (0.30% C, 1.25% Cr, 0.5% Mo, 0.25% V) has been used for inert-gas welding AISI 4340 and AMS 6434 steels.[3] The strength and ductility of the welded joints made with modified filler wires is dependent on base-metal dilution and heat-treat response.

Weld metal generally freezes with a relatively large, dendritic grain structure. The dendrites grow from the cool base metal toward the center of the weld as freezing progresses along the joint. The effect of prior austenitic grain size on the strength and ductility of tempered-martensite weld metal is not fully understood. Stout and Doty report that fine-grained, quenched and tempered 0.40% carbon steel has lower strength, higher ductility and higher Izod impact energy absorption than coarse-grained steel of the same composition.[4] They also report that increased prior austenitic grain size raises the transition temperature of normalized 0.25% carbon steel. A heat treatment was designed in this study to refine the prior austenitic grain size of weld metal, and its effect on the strength and ductility of tempered martensite was determined.

The soundness and homogeneity of the weld metal are important factors in its behavior in pressure vessels. Because of the rapid cooling, the weld metal is heterogeneous in nature. Phases containing elements such as sulfur, phosphorus, carbon and manganese frequently segregate. Sulfur forms the low-melting iron sulfide in steels, which contributes to hot shortness. Phosphorus apparently aggravates the precipitation of sulfides. Manganese is added to the steels to preferentially form manganese sulfide, which melts at a higher temperature than iron sulfide. Consequently, it is desirable to keep the phosphorus and sulfur content of the base metal and filler wire to 0.010% maximum.[3,5]

Materials

Three typical 0.40% carbon, low-alloy steels developed by industry for aircraft and missile applications were selected for this study. The alloys were procured in sheet form in the spheroidize-annealed condition with a hardness of 15 to 20 Rc. Alloys, sheet thicknesses, heat numbers and chemical compositions are shown in Table 1. Steel 300M is a 2% nickel – 0.75% Cr type, and X-200 is a 2%-chromium type of steel. Both alloys contain about 1.5% silicon for optimum tempering in the 500 to 700° F range. Steel D6A is a 1% chromium – 1% molybdenum – 0.5% nickel steel with normal silicon content. Its optimum yield strength is obtained when tempered in the 400 to 600° F range.

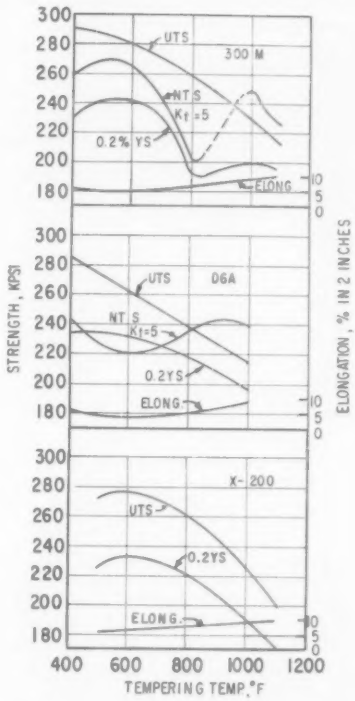

Fig. 2—Average tensile properties of 300M, X-200 and D6A steel sheet

Table 2—Chemical Composition of the Welding Filler Wires

Alloy	Heat no.	Type	C	Mn	Si	Ni	Cr	Mo	V	P	S
300M-1	81021	Air-melt	0.43	0.98	1.79	1.77	0.82	0.40	0.09	0.010	0.012
300M-2	6-080	Vac-melt	0.40	0.79	1.67	1.74	0.82	0.40	0.09	0.003	0.002
X-200	10675	Air-melt	0.44	0.89	1.54	...	1.71	0.37	0.02	<0.02	0.006
LC300M	2V-044	Vac-melt	0.27	0.88	1.68	1.89	0.86	0.34	0.09	0.007	0.012
Ni-Mo	...	Air-melt	0.23	0.64	0.20	2.77	...	0.50	0.07	0.021	0.022
Cr-Mo-V	...	Air-melt	0.25	0.28	0.03	...	0.98	1.29	0.56	0.005	0.009

The filler-wire composition used for the welding studies is described in Table 2. The wires were procured in 0.045 in. diam, flash-copper coated and level wound on spools for automatic welding. Two heats of 300M filler wire were used, one air-melt and one vacuum-melt. The modified vacuum-melted 300M wire had lower carbon content than normal 300M alloy. Three other filler wires represent experimental alloy steels, initially selected for evaluation with 300M steel. They were of the low-carbon type to produce weld deposits with improved ductility. The filler wires used for the X-200 and D6A sheet are also included in the table. The Cr-Mo-V wire contained about the same amount of chromium and molybdenum as D6A steel.

Welding Process and Procedures

After considering the types of arc-welding processes available, the materials, and their thicknesses, the inert-gas-shielded tungsten-arc welding process was selected for producing butt joints in the three alloy steels. Past experience had shown that sound welds could be deposited in steel by this process with a minimum loss in alloying elements from the filler wires. Also, the inert-gas protective shield over the molten weld puddle minimized oxidation of the metal. Welding speed is slower in this process than in metal-arc welding, which decreases the cooling rate of the weld. The slower cooling rate is beneficial in avoiding cracking in high-carbon, air-hardening steel weldments.

An automatic inert-gas welding head and filler-wire feeder were used. A flat-plate welding fixture with cartridge-type heaters was mounted on a variable-speed, motor-driven carriage to move the joint under the tungsten arc. The fixture, welding torch and filler-wire guide tube are shown in Fig. 3. The temperature of the fixture was maintained by a thermocouple and a temperature controller attached to a saturable-reactor power source. Welding current was supplied by a 300 amp d-c rectifier-type arc-welding machine with an open-circuit voltage of 80 v. Arc voltage was controlled to a preset value by the automatic head. The arc was initiated by touch start, and the filler-wire feeder and carriage movement started automatically when the arc was initiated.

The welding procedures were established using base metal and filler wire of 300M alloy. Arc voltage, welding current, wire-feed rate, travel speed, joint design, type of shielding gas and weld backing design were studied. The plates to be welded were sheared to size, and the edges to be joined were belt sanded or sand blasted to remove the heavy oxide scale on the sheet. The edges were beveled at 45 deg for $^1/_8$ to $^1/_2$ the sheet thickness to guide the filler wire into the arc. (The bevel was not required to obtain full penetration.)

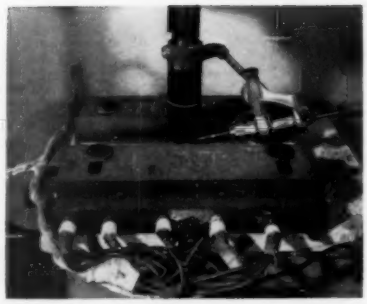

Fig. 3—Setup for inert-arc welding with preheat

To prevent weld cracking, the workpieces and fixture were preheated. Optimum preheat and postheat time and temperature were established for 300M steel by a series of welding tests at preheat and postheat temperatures of 300, 400, 500, 600, 700, 800 and 900° F. Postheat time was 30 min. Longitudinal-bend tests were made on as-welded joints. Good ductility was obtained in the welded joints preheated and postheated at 600 and 700° F, while the other welds cracked with very little ductility. The effect of postheat times of 0 to 60 min at 650° F on the weld microstructure were studied. It was found that the weld- and heat-affected zones transformed to bainite after 30 min at 650° F. It was also found that a bainitic structure was obtained after 30 min at 550 to 650° F. Above 650° F, the amount of bainite decreased and no bainite was observed with a 900° F, 30-min postheat followed by air cooling. The preheat and postheat temperatures for X-200 and D6A steels were determined from the isothermal transformation diagrams.

Argon and helium gases were evaluated for shielding the weld puddle through the inert-gas torch. Although satisfactory welds were obtained using argon, helium proved to be the better shielding gas because it gave better weld geometry and penetration. The weld bead was narrower with helium shielding.

Weld backing technique was also investigated. A grooved copper backing bar was first tried with 300M steel, but transverse cracks occurred on the backside of the weld using a 600° F preheat. Argon-gas backing through holes in a copper backing also resulted in cracking when the weld metal dropped onto the bar. When the weld metal did not touch the bar, no cracking was observed. However, control of drop-through of weld metal was difficult.

To reduce the cooling rate on the backside of the welds, a ceramic-type bar was developed. It consisted of a stainless-steel bar with about 40 mils of zirconia flame sprayed on the surface. The zirconia acted as a thermal insulator, and the molten metal did not adhere to it. No weld cracking was observed when welding with this ceramic backing. The backing-bar face was recessed about 20 mils below the surface of the welding fixture to control the drop of the weld puddle and obtain complete penetration.

The welding procedures developed for 300M steel sheet were used for welding X-200 and D6A sheet with slight modifications in travel speed, filler-wire feed rate and welding current. The welding schedules are shown in Table 3. Adequate penetration and weld-face buildup were obtained in all test plates.

Table 3—Welding Conditions for Single-pass Inert-gas-shielded Tungsten-arc Welds in Sheet Material

Alloy	300M	X-200	D6A
Sheet thickness, in.	0.080	0.093	0.093
Preheat temp., ° F	600	600	550
Arc voltage, v	14–16	14.5	15
Arc current, amp	80–90	100	100
Filler-wire diam, in.	0.045	0.045	0.045
Wire-feed rate, ipm	27–30	36	38
Work-travel speed, ipm	10	12	12
Shielding gas	He	He	He
Torch-gas flow, cfh	50	50	50
Trail-gas flow, cfh	75	75	75
Postheat time, min	30	30	30
Tungsten-electrode diam, in.	$^3/_{32}$	$^3/_{32}$	$^3/_{32}$

All weld joints used for mechanical-property determinations were X-ray radiographed for soundness. Prior to radiographing, the weld-bead build-up and drop through were sanded flush with the sheet surface. The amount of porosity in the weld was dependent on the cleanliness of the welding wire and base metal. Dirt, rust and drawing compound on the filler wire caused excessive

porosity. Flash copper coating on the filler wire did not insure absence of rust and drawing compound. The wire was sanded with emery cloth and washed with acetone just prior to welding. Mill scale from hot rolling also caused excessive porosity when the sheet materials were not cleaned satisfactorily. Adequate torch and trail-gas coverage was used to prevent surface oxidation of the weld bead.

Weldments used for mechanical-property tests were chosen on the basis of soundness and good build-up and penetration of the weld metal.

Heat-treatment Studies

A detailed study of the heat treatment and metallurgical structures of welds in this type of steels was made. The effects of various heat-treatment procedures on mechanical properties of welds were determined. As with welding procedure development, the majority of the heat-treatment studies were made on welds in 300M steel and the results were applied to weldments in X-200 and D6A steels.

The welded test plates and individual test specimens were painted with a commercial water-soluble preparation designed to prevent surface decarburization. The coated pieces were austenitized in a retort-type electric furnace with a flowing-argon atmosphere and cooled in still air. Tempering at 700° F or below was done in an air-atmosphere furnace and in flowing argon at higher temperatures.

The effect of single austenitizing temperature, double austenitizing and weld-grain refinement prior to final austenitizing were evaluated on 300M steel. Based on the results of the 300M alloy heat-treat studies, single austenitizing of as-welded joints and grain-refined weldments in X-200 and D6A alloys were evaluated. The austenitizing heat treatments for welds in the three alloys evaluated by mechanical property tests are shown in Table 4.

The weldments were tempered twice for 2 hr with an intermediate aircool to room temperature to avoid untempered martensite in the microstructure. The tempering temperature for each alloy was the range where the maximum yield strength is obtained in the base metal. These were 600 and 625° F for 300M, 700° F for X-200 and 600° F for D6A alloy. Also 300M weldments were tempered at 1025° F to evaluate the notch properties of welds at a strength level where the notched to unnotched tensile-strength ratio of the base metal is greater than one.

Air cooling the weldments from austenitizing temperature resulted in the typical martensitic structure of high-carbon, air-hardening steels. The final metallurgical structure was tempered martensite of slightly lower hardness than the as-quenched martensite. Typical microstructures of 300-M weld metal in the as-welded and austenitized and tempered conditions are shown in Figs. 4 and 5.

Austenitizing temperatures and times can influence the extent to which the stable carbides of chromium, molybdenum and vanadium are dissolved in the austenite. This in turn, can influence mechanical properties of the steel. Also, the strength and ductility of the weldment can be dependent on the prior austenite grain size of the weld and heat-affected zones. A grain-refining heat treatment was identified to study in detail the relationship between weld mechanical properties and austenite grain size.

To refine the austenitic grain size of 300M, it was necessary to transform austenite to fine ferrite and pearlite by austenitizing at 1650° F, cooling to 1200° F, and holding for about 8 hr to obtain an esssentially complete transformation. The microstructure of a weld in 300M steel after this treatment is shown in Fig. 6. Subsequent austenitization of the ferrite and pearlite resulted in fine austenite ranging from grain size ASTM 7 to 8. Refinement of the austenitic grains was dependent upon the prior structure, inasmuch as austenitization of tempered martensite and bainite did not result in the significant grain refinement obtained from the pearlitic structure. Similar grain refining heat treatments were developed for X-200 and D6A

Fig. 4—Typical bainitic weld-metal microstructure of arc welds in 300M steel sheet postheated at 600° F. X 100. (Reduced by 1/2 upon reproduction)

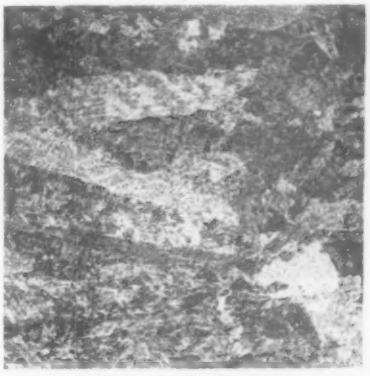

Fig. 5—Typical martensitic microstructure of weld metal in 300M steel sheet tempered at 600° F. X 100. (Reduced by 1/2 upon reproduction)

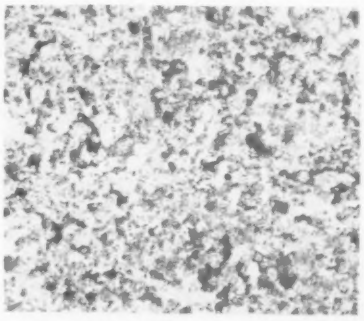

Fig. 6—Microstructure of weld metal in 300M steel after transformation to fine ferrite and pearlite. X 100. (Reduced by 1/2 upon reproduction)

Table 4—Austenitizing Heat Treatments for Arc Welds in 300M, X-200 and D6A Steel Sheet

Heat treatment	Type	300M	X-200	D6A
Standard	A	1650° F—1/2 hr, A.C.	1750° F—1/2 hr, A.C.	1650° F—1/2 hr, A.C.
Double austenitize	B	1700° F—1/2 hr, A.C.; 1600° F—1/2 hr, A.C.		
Grain refinement	C	1650° F—1/2 hr, F.C. to 1200° F—8 hr, A.C.; 1650° F—1/2 hr, A.C.	1750° F—1/2 hr, F.C. to 1300° F—8 hr, A.C.; 1750° F—1/2 hr, A.C.	1650° F—1/2 hr, F.C. to 1300° F—8 hr, A.C.; 1650° F—1/2 hr, A.C.

welds that produced like microstructures.

After grain refinement, the welds were tempered in the usual manner. The tempered microstructure of a typical martensitic weld zone is shown in Fig. 7. Welds in X-200 and D6A material given the same type of heat treatments had similar microstructures. While the austenitic grains were refined, it was not apparent that the size of the much smaller martensitic plates was dependent upon the prior austenitic grain size. None of the above heat treatments, or austenitizing at 2000° F, significantly changed the dendritic appearance of the weld metal.

Testing Procedures

Welded joints in the three alloys were evaluated by transverse and longitudinal tension tests, notched-tensile test and longitudinal-bend tests. In the longitudinal tests, the weld joint ran the length of the specimen, and the weld metal, heat-affected zones and base metal were subjected to the loading. In the transverse tests, the weld ran across the specimen in the reduced section. The welded joint was ground flush with the base metal in all tests.

The unnotched tensile specimens had a $^1/_2$-in. wide reduced section with a 1 or 2 in. gage length. The elongation of the weld in the transverse tensile specimens was measured between $^1/_2$-in. scribed gage marks spanning the weld. Notched tensile strengths of the welded joints were determined using transverse-weld tension specimens with two V notches machined in the weld metal opposite each other (Fig. 8). The 5-mil radius notches were ground in the specimens to produce a stress concentration factor, K_t, of 6. To obtain a stress concentration of 8.4, 5-mil wide slots (2.5 mil radius) were electric-spark-discharge machined in the bottom of 10-mil radius ground notches. The total notch depth was about 0.10 in. leaving a 0.30-in. test section between the notches.

The plastic deformation in the bend specimens was estimated from the radius of bending for the 300M specimens in the three-point bend test. For the constant-moment bend tests, the plastic deformation was calculated from the strain-gage measurements or extrapolated from the bend angle – strain data, if the strain exceeded the life of the gage.

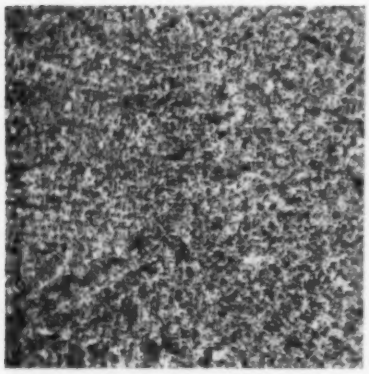

Fig. 7—Martensitic microstructure of grain-refined weld metal in 300M steel sheet tempered at 600° F. X 100. (Reduced by $^1/_2$ upon reproduction)

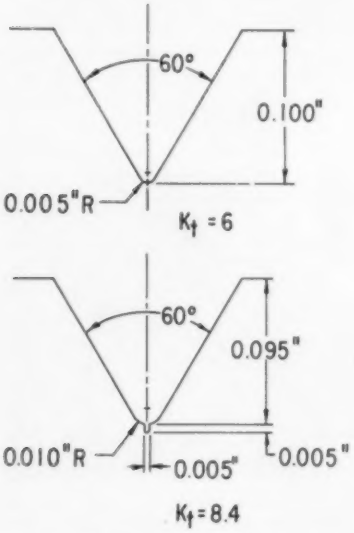

Fig. 8—Notch geometry for notched-tensile sheet specimens

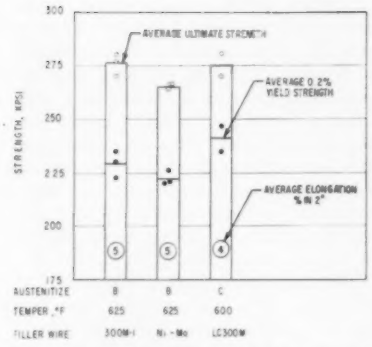

Fig. 10—Longitudinal-tensile data on arc welds in 0.080-in. 300M steel sheet

Experimental Results

300M Alloy Steel

The studies on the welding of 300M steel were divided into two areas; (1) evaluation of welding filler wires, and (2) development of an optimum austenitizing and tempering heat treatment. Welds were made in the 300M steel sheet using 300M, low-carbon 300M and Ni-Mo filler wires. Weldments were given austenitizing treatments shown in Table 4 and double tempered. The tensile test results on the welds in 300M steel sheet are shown in Figs. 9 and 10.

The transverse and longitudinal tensile tests on arc welds made with the three filler wires showed that both filler-wire composition and heat treatment influence the strength

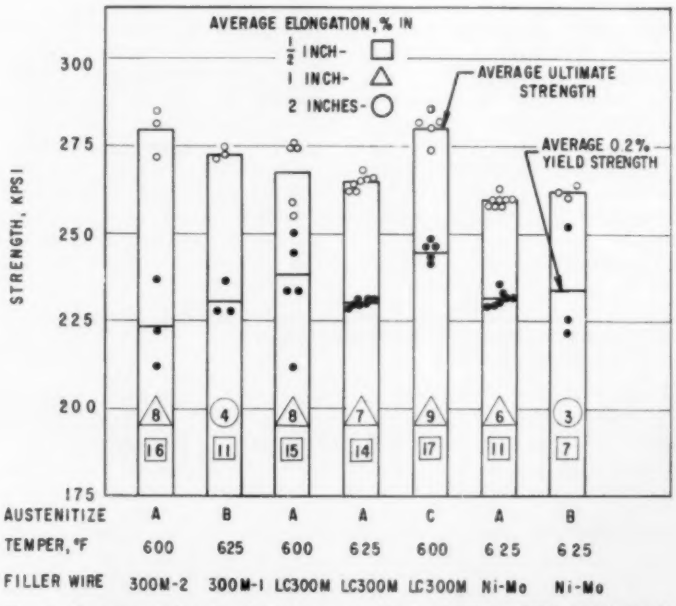

Fig. 9—Transverse-tensile data on arc welds in 0.080-in. 300M steel sheet

properties of welds. Average yield strengths of 223,000 to 244,000 psi were obtained in welded specimens made with the three filler wires. Austenitizing standard-carbon 300 M filler welds at 1700° F (double austenitizing) increased the average yield strength to 230,000 psi from 223,000 psi for specimens single austenitized at 1650° F. Because the fractures were in the base metal, the higher austenitizing temperature apparently improved the base-metal strength by increasing the extent of carbide solutioning. No significant change in yield strength was obtained in the Ni-Mo filler welds by the double-austenitizing treatment, possibly because of the low-carbon concentration of weld metal. The double austenitization decreased the weld ductility, and the yield strength values were not as consistent as with the single austenitizing treatment.

The two series of specimens with low-carbon 300M filler tempered at 600 and 625° F had equivalent mechanical properties, with the specimens tempered at 625° F exhibiting more consistent strengths than those tempered at 600° F. The reason is unknown, but the one 600° F tempered specimen with 212,000 psi yield strength had the greatest ductility of all specimens and a high ultimate strength.

The most significant improvement in mechanical properties was obtained by using the weld-grain refining heat treatment with low-carbon 300M filler wire. The average yield strength was higher than for welds with the standard carbon 300M filler, given the regular austenitizing and tempering treatments. The effect of grain refinement on the properties of standard-carbon 300M filler weldments was not determined.

Low-carbon filler wire of the 300M composition produced welds which had strengths comparable to those of the base metal. The welds had a greater capacity for plastic strain required to relieve residual stresses resulting from welding and heat treating of pressure vessels. The Ni-Mo filler wire produced welds with good strength and ductility, but differences in filler-wire and base-metal chemistry suggests possible variations in weld-metal composition. As a result of the tests, it was concluded that the low-carbon 300M filler wire was proper for welding this steel for thin-wall pressure-vessel applications.

The effect of the grain-refining heat treatment on the notched-tensile properties of welds with low-carbon 300M filler was studied. Notched specimens were tested at 72, 0 and −100° F, with and without the grain-refining heat treatment at 600 and 1025° F temper. Tempering at 1025° F provided material where the notched-to-unnotched strength of the base metal is greater than one (see Fig. 2). The results are shown graphically in Fig. 11. All specimens were welded and heat treated together, as far as possible.

Generally, grain refinement of the weld improved the notch properties at a temperature of −100° F but, at room temperature, there was no significant improvement from the grain refinement. The notched-to-unnotched ratio was less than one for both tempering treatments, but the ratio was higher for 1025° F temper.

Below room temperature, grain-refined welds had increased notch strength, compared to the coarse-grained welds. It appears that the notch transition temperature of fine-grained welds was lower than for normal-grain-size welds at both 600 and 1025° F tempering temperatures. The improvement in notch properties at −100° F with grain refinement was very significant with the 1025° F temper, and there was also a noticeable difference in fracture appearance, in that the large-grained weld metal had a brittle, coarse-type fracture. The fine-grained welds had some ductile, shear type of failure.

The results of three-point loaded bend tests on longitudinal speci-

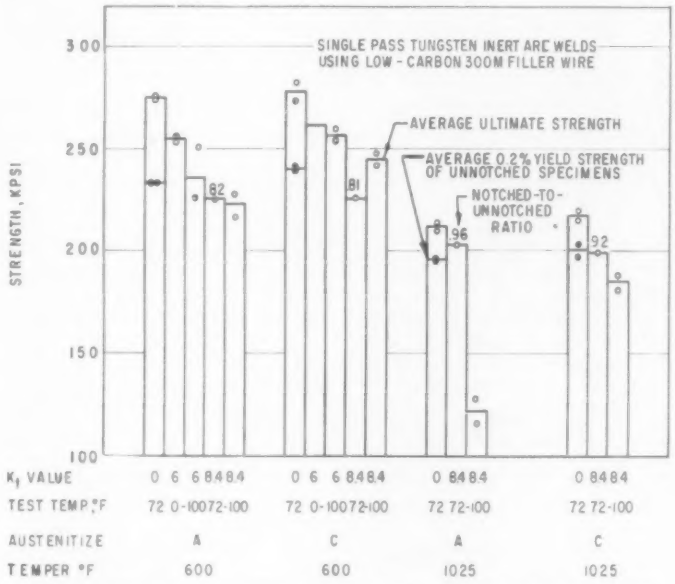
SINGLE PASS TUNGSTEN INERT ARC WELDS USING LOW - CARBON 300M FILLER WIRE
AVERAGE ULTIMATE STRENGTH
AVERAGE 0.2% YIELD STRENGTH OF UNNOTCHED SPECIMENS
NOTCHED-TO-UNNOTCHED RATIO
STRENGTH, KPSI
300
250
200
150
100
82
81
96
92
K_t VALUE 0 6 6 8 4 8 4 0 6 6 8 4 8 4 0 8 4 8 4 0 8 4 8 4
TEST TEMP, °F 72 0 -100 72 -100 72 0 -100 72 -100 72 72 -100 72 72 -100
AUSTENITIZE A C A C
TEMPER °F 600 600 1025 1025

Fig. 11—Notched-tensile properties of arc welds in 0.080-in. 300M steel sheet

Table 5—Bend Ductility of Longitudinal Arc Welds in 0.080-in. 300M Alloy Steel Sheet[a]

Filler wire	Austenitizing treatment	Tempering temp., °F		Bend radius in.	Bend radius T[b]	Theoretical elongation, %
300M-1	B	625F		1 1/2	16	3.0
				1 1/2	16	3.0
				1 1/2	16	3.0
				1 1/2	16	3.0
				3/16	6	7.7
				5/16	3.3	13.2
			Av	1 3/8	12	5.5
Ni-Mo	B	625F		1 1/2	16	3.0
				7/16	4.5	10.0
				7/16	4.5	10.0
				1/4	4	11.1
				5/16	3.3	13.2
				5/16	3.3	13.2
			Av	11/16	6	10.1

[a] Single-point load bend test with 120 deg bend angle.
[b] Bend radius expressed in terms of sheet thickness T.

mens welded with 300M and the Ni-Mo filler wires are shown in Table 5. These welds received similar heat treatments. The average bend radius of the specimens with the low-carbon Ni-Mo filler wire was 6T, compared to 12T for welds with 300M filler. The improved bend behavior of joints with the Ni-Mo filler was attributed to improved weld-metal ductility and soundness. The cause of the scatter in bend radius for both sets of welds is not known, but it may have resulted from small defects in the welds that were not detected by radiography.

X-200 Alloy Steel

Arc-welded joints were made in X-200 sheet, using the same procedures as for welding 300M steel. Two weld-filler-wire compositions were chosen, X-200 and the low-carbon 300M, to evaluate joints having weld metal of the same composition as the base metal and weld metal with a lower-carbon content than the base metal. The nickel in the low-carbon 300M steel could increase the toughness and impact resistance of the weld metal.

The austenitizing and tempering temperatures used for X-200 weldments were those that provide the maximum yield strength in unwelded sheet. The grain refinement treatment for welds was determined from the isothermal transformation diagram for X-200 steel. The austenitizing heat treatments are shown in Table 4. All weldments were double tempered at 700° F for 2 hr, with an intermediate air cool to room temperature.

Transverse and longitudinal tensile tests, notched-tensile tests and longitudinal constant-moment bend tests were made on heat-treated weldments. The results of the tests are shown in Figs. 12 and 13. The notched specimens had 0.005 in. radii, resulting in a stress concentration factor K_t of 6.

The tensile-strength properties of welded joints in X-200 sheet were influenced by both filler-wire composition and heat treatment. Welds with X-200 filler, given the standard heat treatment, had the highest tensile-strength properties. They were equivalent to the properties of unwelded sheet. The weld-grain-refining heat treatment lowered the strength of the transverse-tension specimens, but the fractures were outside of the weld. Thus, the welds were as strong as the base metal. There was no significant difference in longitudinal weld tensile and bend-strength properties with standard and grain-refining heat treatments, which also indicated that the grain-refined welds were as strong as the base metal.

The significant effect of grain refinement of X-200 filler welds was in the notched-tensile strength. Grain refinement increased the average notched-tensile strength to 257,000 psi from 227,000 psi. The notched - to - unnotched tensile-strength ratio increased to 0.91 from 0.76. Thus, grain refinement increased the ability of the weld to adjust to stress concentrations.

Addition of low-carbon 300M filler wire in the weld decreased the yield and ultimate tensile strengths of the joints below those of X-200 filler welds. The greatest change was observed in yield-strength values in the longitudinal tension and bend tests. At the same time, there was a significant improvement in weld-joint ductility. This was attributed to the lower carbon concentration in the weld metal which decreased the hardness and increased strain-hardening capacity. Welds with low-carbon filler,

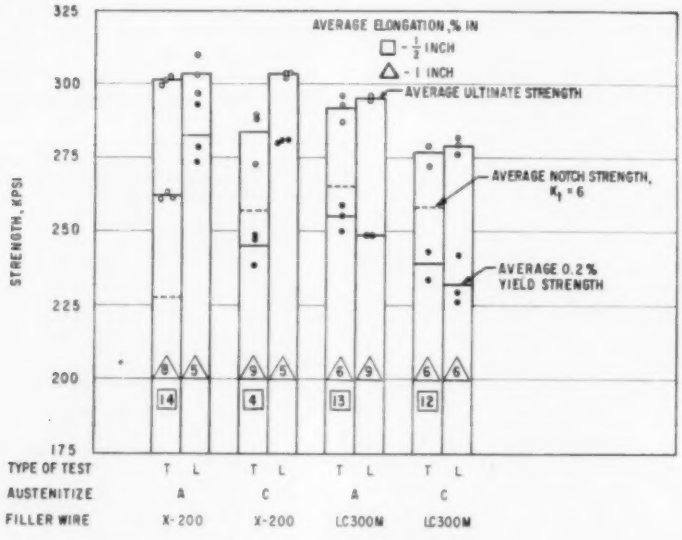

Fig. 12—Tensile-strength data on arc welds in 0.093-in. X-200 steel sheet (700° F temper)

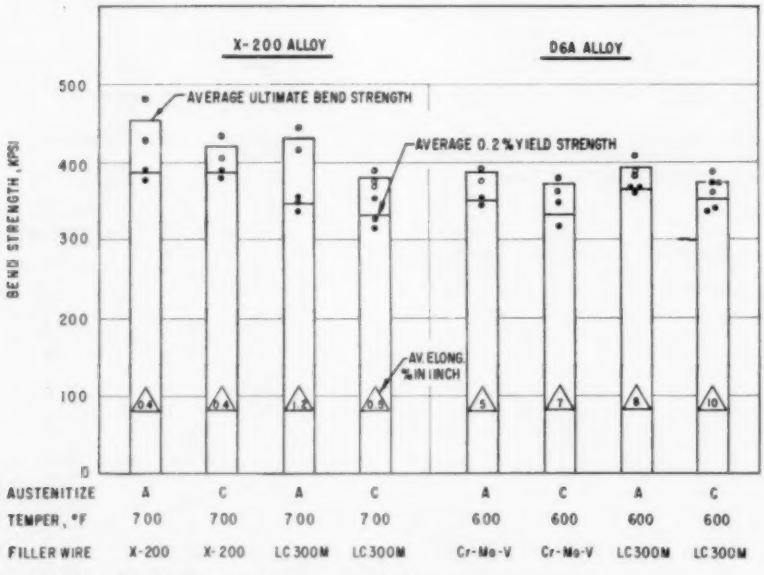

Fig. 13—Longitudinal-bend test on arc welds in 0.093-in. X-200 and D6A steel sheet (four-point loading)

given the standard heat treatment, were as strong as the heat-treated base metal. The grain refinement of the low-carbon filler welds resulted in yield strengths below that of unwelded sheet.

The low-carbon filler wire also produced improved notch-tensile strength properties in the welds. The notch-to-unnotched tensile-strength ratios were equivalent to that of grain-refined X-200 filler welds.

All welds had very low bend ductility. The elongations obtained were much lower than expected in a steel of 6% elongation in unwelded material. The reason for the low bend ductility is not known, but the origin of all fractures were in the weld metal, indicating a lack of bend ductility in this zone.

Considering all the data, welded joints with low-carbon filler wire given the standard heat treatment had the best over all combination of strength properties, ductility and notch toughness.

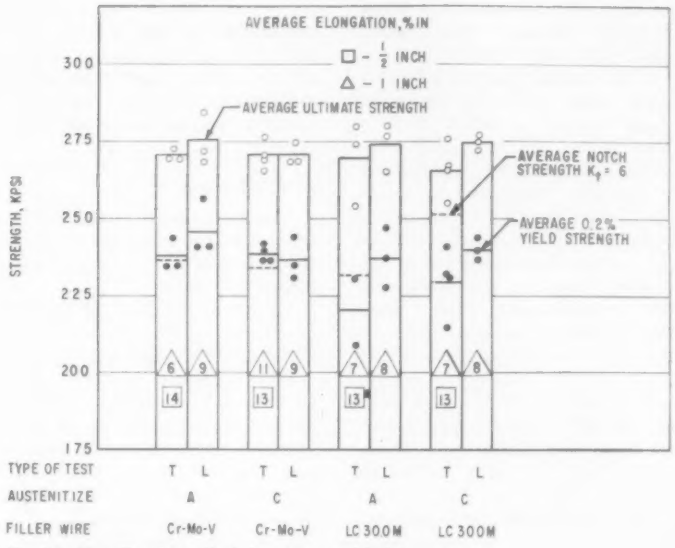

Fig. 14—Tensile-strength data on arc welds in 0.093-in. D6A steel sheet (600° F temper)

D6A Steel

Arc-welded joints were made in 0.093-in. thick D6A alloy steel sheet using two low-carbon filler wires. One wire was the Cr-Mo-V composition which is similar to D6A alloy except for the absence of nickel and addition of about 0.5% vanadium. The other wire was the low-carbon 300M composition which contains higher nickel and silicon and lower molybdenum contents than D6A. The welds were heat treated with and without weld-grain refinement, using austenitizing treatments shown in Table 4. The welds were double-tempered at 600° F for 2 hr with an intermediate air cool. Unwelded sheet has the highest yield strength when tempered at this temperature, but the notch-tensile strength (at K_t = 5, see Fig. 2), is considerably lower than the ultimate strength.

Transverse, longitudinal and notched-tensile tests and longitudinal-bend tests were made on welded joints. The results of the tests are shown in Figs. 13 and 14. The average tensile properties of the welded joints with both filler wires and heat treatments were similar. Tensile strengths ranged from 265,000 to 275,000 psi, and the yield strengths ranged from 220,000 to 240,000 psi with weld ductility similar for all conditions. The tensile and yield strengths of the welded joints were about the same as reported for the unwelded base metal (Fig. 2). As with 300M and X-200 weldments, the addition of low-carbon filler wire was not detrimental to weld-joint tensile strength.

The average yield strengths in bending ranged from 330,000 to 363,000 psi, compared to 220,000 to 240,000 psi in tension. Filler-wire composition had negligible effect on bend-strength properties. The most significant results of the bend tests was the superior ductility of D6A weldments over X-200 weldments at comparable strength levels. Weld-grain refinement decreased the average yield strength in bending, about 20,000 psi with both filler metals, but improved the ductility.

Grain refinement had no significant effect on mechanical properties of welded joints made with the Cr-Mo-V filler wire. Apparently, strain hardening and notch toughness of the weld metal was not affected by weld-grain size. The weld metal had good ductility in tension and bending.

Welds made with low-carbon 300M filler wire had slightly lower tensile-strength properties than the welds made with Cr-Mo-V filler. The most significant improvement observed with the low-carbon 300M filler was the improvement in notch-tensile strength with grain-refining heat treatment. It increased to 251,000 psi from 231,000 psi for standard heat treatment. The notched - to - unnotched tensile-strength ratio with grain refinement was 0.95 compared to 0.86 for large-grained welds.

On the basis of unnotched-tensile and bend data, the low-carbon Cr-Mo-V filler wire, combined with the grain-refining heat treatment gave the best results. On the other hand, low-carbon 300M filler wire and grain refinement gave the best notched-tensile properties. The nickel in the filler wire might have contributed to this behavior.

The tests described showed that, as with 300M and X-200 alloys, a low-carbon filler wire produced welded joints with strength properties comparable to the base metal. Although grain refinement improved notch strength of low-carbon 300M filler welds, the Cr-Mo-V alloy is a better choice because the over-all chemistry of the filler wire is sufficiently similar to the base metal to assure appropriate heat-treating characteristics of the weld, i.e., adequate hardenability and similar tempering characteristics.

Discussion of Results

The experimental work showed that sound arc-welded joints can be produced in ultra-high-strength low-alloy steels with strengths and ductilities equal to those of the base metal. Proper preheating, post-heating and weld backing techniques were required to avoid weld cracking. Two of the steels, X-200 and 300M were welded using filler wires of the same compositions as the base metal. The welds had good transverse and longitudinal tensile-strength properties, but the weld ductility was low. This was shown by the longitudinal tension and bend tests.

Improved weld ductility was obtained, using filler wires with relatively low-carbon levels in the range of 0.23 to 0.27%. The dilution of base metal with the lower-

carbon filler wire decreased the weld-metal carbon content. As a result, the weld metal had improved ductility. The welded joints had yield strengths comparable to those of the base metals. With X-200, the low-carbon 300M filler wire produced joints with improved notch strength, compared to welds made with X-200 filler. The notch strength of arc welds with 300M filler of normal composition was not determined because the difficulty initially encountered with weld cracking shifted the emphasis to evaluation of the low-carbon 300M filler.

Good bend ductility was obtained for 300M and D6A welds, using low-carbon filler wires. However, the bend ductility of welds in X-200 sheet with low-carbon 300M filler was poor for unknown reasons.

Grain refinement of the weld metal generally improved weld ductility and notch-tensile strength. Significant improvement was obtained in the notch strength of X-200 welds with X-200 filler wire. Grain refinement increased the notched-to-unnotched tensile-strength ratio to 0.91 from 0.76 for unrefined weldments. Improvement in notched strength was also obtained with 300M welds made with the low-carbon 300M filler, particularly under the more severe stress concentration conditions at −100° F. A very significant improvement in notch strength at −100° F was obtained with the 1025° F tempering temperature. Welds in D6A with low-carbon 300M filler also had improved notch strength after the grain refinement heat treatment. In conclusion, both low-carbon filler and grain refinement improved notch properties and, under the most severe conditions of stress concentration and temperature, the combination of low-carbon filler wire and grain refinement resulted in the best combination of notch strength and ductility.

Conclusions

The experimental results lead to the following conclusions regarding the welding of ultra-high-strength low-alloy steels:

1. Strong, sound welds can be produced in the steels to obtain 100% joint efficiency.

2. A preheat of 600° F and a ceramic-type backing should be used to avoid cracking in the weld. Careful cleaning of the base metal and filler wire and good inert-gas coverage should be used to minimize porosity and inclusions.

3. Welded joints should be post-heated at a temperature just above the Ms temperature for a sufficient time to transform austenite to bainite in preference to harder martensite. The softer bainite reduces the possibility of weld cracking prior to heat treatment.

4. Utilization of welding-filler wires of lower carbon content than the base metal improves weld ductility and notch strength. The weld joint strengths are comparable to those of the base metal. The over-all chemistry of the filler wire should be sufficiently similar to the base metal to assure appropriate heat-treating characteristics, i.e., adequate hardenability and similar optimum tempering temperatures.

5. Refinement of the prior austenite grain size in the weld region improves the ductility and notch strength of welded joints. The degree of improvement is affected by filler-wire composition, heat treatment and the service conditions of temperature and stress concentration. With moderate stress concentration and room-temperature service, grain refinement appears unnecessary for the best combinations of base metal and filler wire. However, with high stress concentration and low-temperature service, grain refinement of the weld is necessary to obtain the best strength properties in the welded joint.

6. Overtempering of the welds in 300M steel sheet at 1025° F does not improve the notch strength of the weld metal. The notch strength is actually lower than that of welds tempered at 600° F.

Acknowledgments

The authors wish to express their appreciation to Clay Fulcher, Paul Blanz and Dallas Weddle of the General Electric Co. for their valuable assistance in the welding and heat-treating studies. The authors are also grateful to M. D. Randall and his associates at Battelle Memorial Institute, Columbus, Ohio, for their aid in the evaluation of welding-wire compositions and heat treatments for 300M steel.

References

1. Sands, J. W., "Development of a Steel for the 280,000 to 300,000 psi Tensile Strength Bracket," Symposium—Ultra High Strength Steels in Aircraft Applications, SAE SP-120, pp. 35–46 (1953).

2. Nehrenberg, A. E., "New Super-High Strength Structural Steels," *Materials and Methods*, 100–103, (October 1954).

3. Mishler, H. W., Monroe, R. E., and Rieppel, P. J., "Welding of High-Strength Steels for Aircraft and Missile Applications," DMIC Rept. 118, Battelle Memorial Institute (Oct. 12, 1959).

4. Stout, R. D., and Doty, W. D., *Weldability of Steels*, Welding Research Council, pp. 114–116 (1953).

5. Sopher, R. P., "Effects of Chemical Composition on Cracking Resistance of High-Strength Steel Weld Metals," THE WELDING JOURNAL, 37 (11), Research Suppl., 481-s to 492-s (1958).

WRC Bulletin No. 62

Comparison and Analysis of Notch Toughness Tests for Steels in Welded Structures

This Bulletin, published in July 1960, takes into account brittle failures in welded structures and establishes the degree of correlation among results of different laboratory tests for evaluating notch toughness. The Charpy-V, Kinzel and drop weight tests supply valuable information with respect to base plate notch toughness and brittle failure in welded structures. The Kinzel test is also useful in evaluating the relative merits of welding procedures and of heat treatment before and after welding. However, it must be recognized that no notch toughness test can predict the transition temperature of a specific structure. Thus, the question of whether or not to apply transition temperature concepts to the selection of material for a specific structure is a matter for sound engineering judgment and specific rules cannot be laid down.

The price of this Bulletin is $1.00 and single copies may be purchased through the American Welding Society, 33 West 39th Street, New York 18, N. Y. Quantity lots may be purchased through the Welding Research Council, 29 West 39th Street, New York 18, N. Y.

Comparison and Analysis of Notch-Toughness Tests for Welded Steel

Interpretive survey of the notch-toughness literature attempts to clarify the degree of correlation among the results of different tests that have been devised

BY H. H. JOHNSON AND R. D. STOUT

FOREWORD. As one phase of the investigation at Lehigh University on the weldability of structural steels, an extensive survey and interpretation of the literature on notch-toughness tests was conducted and published as a WRC bulletin.[1] Because of the substantial interest in this topic, a condensed version of the bulletin is presented here. For a description of the various tests and testing procedures the original paper and its references should be consulted.

Introduction

The occurrence of brittle failures in welded structures has inspired many investigations of the notch toughness of steels and, as a result, many different notch-toughness tests have been devised. Unfortunately, results from the different tests are not always in agreement. An example is shown in Fig. 1, which compares the notch toughness of several steels as measured by several well known tests.[2] A general trend is evident, but the degree of scatter precludes specific correlations. Because of this and other examples, the quantitative interpretation of notch-toughness tests is often considered ambiguous.

It is desirable to establish the degree of correlation among results of different tests, and to assess the influence upon correlation of factors such as chemical composition, steelmaking practice, welding, plate thickness, heat treatment, etc. Further, a most important point is the significance of test results in terms of service behavior. In this paper an attempt is made to clarify these issues through an interpretive survey of the notch-toughness literature.

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General Analysis of Test Behavior

Although laboratory specimens and service structures differ greatly in size and complexity, service-failure experience has facilitated the development and interpretation of laboratory tests. The importance of stress concentrations and low temperatures in causing brittle failures is well documented by experience,[3-5] and has led to the use of notched specimens tested over a range of temperatures.

Service experience has also been useful in the selection of a property to use as a measure of notch toughness. The virtual absence of ductility in service fracture surfaces has led to indices of notch toughness based upon ductility, absorbed energy or fracture appearance. These measures of notch toughness show a transition from ductile to brittle behavior as the testing temperature is decreased, e.g., Figs. 2 and 3.[7,8] For tests which show a discontinuous behavior with temperature, Fig. 3, the transition temperature is defined as that of discontinuous behavior. For other tests, Fig. 2, a smooth decrease in notch toughness is observed, and the transition temperature must be defined at an arbitrarily selected level of notch toughness. Examples are the temperatures of 1% lateral contraction, 15 ft-lb absorbed energy, 50% shear fracture, etc. These criteria need not yield identical transition temperatures, and thus transition temperatures are valid only for the conditions of test, and are not necessarily of significance to service.

The analysis of notch-toughness tests is simplified if brittle fracture is considered a two-stage process,[9] a first stage of crack initiation and a second of crack propagation. Some criteria are associated with brittle-crack initiation; these are termed ductility criteria. Examples are

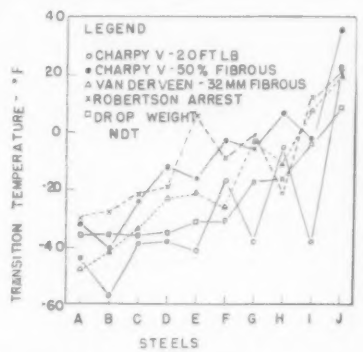

Fig. 1—Relative behavior of ten structural steels when evaluated by four different notch-toughness tests[2]

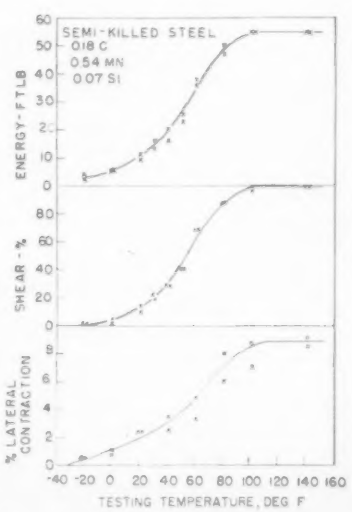

Fig. 2—Transition characteristics of Charpy-V specimens[7]

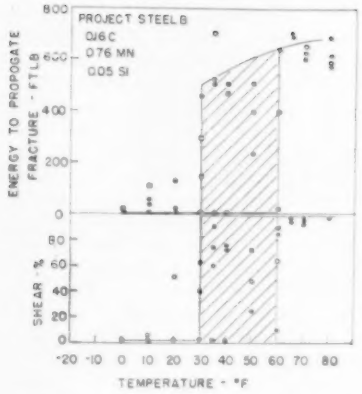

Fig. 3—Transition characteristics of Navy tear test specimens[9]

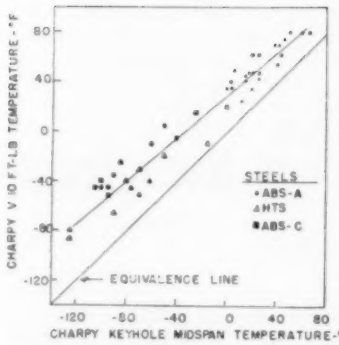

Fig. 5—Correlation of Charpy-V 10 ft-lb and Charpy-keyhole midspan transition temperatures[13]

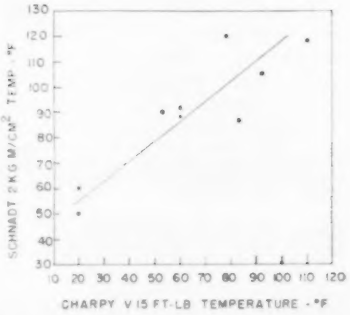

Fig. 6—Correlation of Schnadt 2 [(Kg − m)/cm²] and Charpy-V 15 ft-lb transition temperatures[12]

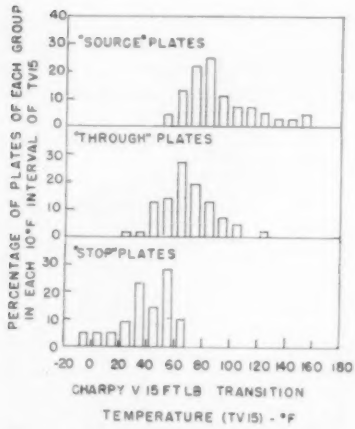
PERCENTAGE OF PLATES OF EACH GROUP IN EACH 10°F INTERVAL OF TV15
"SOURCE" PLATES
"THROUGH" PLATES
"STOP" PLATES
CHARPY V 15 FT LB TRANSITION TEMPERATURE (TV15) - °F

Fig. 4—Frequency distribution of the Charpy-V 15 ft-lb transition temperatures of the ship failure plates[10]

Charpy-V 10 ft-lb, 1% lateral contraction, and bend angle at maximum load. A ductility transition defined by one of these is the highest temperature at which little or no plastic deformation precedes crack initiation.

Criteria descriptive of crack propagation are termed fracture criteria. These determine a fracture transition temperature below which crack propagation is predominantly by cleavage. Examples are fracture appearance and energy after maximum load; the most common is 50% shear fracture.

Two observations suggest that the ductility transition temperature is more significant to service performance. First, ductility transition temperatures usually fall in the same temperature range as service failures, while fracture transition temperatures are much higher. Second, test specimens often exhibit substantial plastic deformation at temperatures below the fracture transition temperature. However, service fractures do not show significant plastic deformation.

Correlations among tests should be based upon either ductility or fracture criteria, and not upon mixtures of the two. This is because the ductility transition temperature is quite sensitive to mechanical factors and welding variables, while the fracture transition temperature is relatively insensitive.[3] Increasing notch sharpness, cold work, larger section size, higher loading rates, introduction of welding, all are factors which usually raise the ductility transition temperature, since they increase the stress state at the crack-initiating notch, and thus decrease the notch ductility. However, the fracture transition temperature is insensitive to these factors, since it is governed by the propagating crack and not by the original notch characteristics.[3]

Comparisons of Tests Measuring the Ductility Transition

For plain-carbon rimmed and semikilled steels, the NBS investigations[10,11] on ship casualty steels have established a striking correlation between base plate notch toughness and susceptibility to brittle failure in service. The Charpy-V test was used throughout; attention was directed primarily to notch toughness at the service-failure temperature.

The experimental results classified the casualty plates into three categories. "Source" plates in which brittle cracks originated exhibited low Charpy-V impact energies with an average value of 7.4 ft-lb at the service-failure temperature. Plates through which cracks propagated, or "through" plates, exhibited greater notch toughness, with an average impact energy at the service-failure temperature of 10 ft-lb. Finally, plates of sufficient notch toughness to stop brittle cracks displayed impact energies from 5.0 to 51.7 ft-lb. Figure 4 presents these concepts in the form of distribution curves of the Charpy-V 15 ft-lb temperature for the three plate categories. These are the most extensive data relating service behavior and test results yet available. This class of steels may be protected from brittle fracture by specifying a minimum Charpy-V impact energy such as 15 ft-lb at the lowest expected service temperature. However, this suggestion should not be applied to other classes of steels without further experimental study.

The NBS correlations are empirical, and involve only base-plate notch toughness and brittle-failure susceptibility. Thus, any adverse influence of factors such as cold working, welding, oxygen cutting, etc., is not evaluated. Undoubtedly, one or more of these factors were present in the plates investigated, and may be responsible for some of the scatter in results.

Since the NBS correlation between ship-service experience and Charpy-V test results is soundly established, attempts have been made to correlate Charpy-V results with other tests. Some of these correlations are discussed below.

Charpy-V vs. Charpy-keyhole Tests

Although the Charpy-V and keyhole-transition curves show basic differences,[3, 12] a fairly good correlation exists when ductility transition temperatures are compared,[13] Fig. 5. The keyhole transition temperatures generally fall 20 to 40° F below the Charpy-V transition temperatures, since the keyhole notch is a less severe stress concentrator. Use of the keyhole test for specification purposes would require that at least 30° F be added

to the midspan temperature to assure relative freedom from brittle fracture.

Charpy-V vs. Schnadt Tests

Although the intended interpretation of the Schnadt test is ambiguous,[14] data for rimmed and semikilled steels[12] show a ductility transition at temperatures well above the Charpy-V 10 or 15 ft-lb temperatures, as shown in Fig. 6, for a Schnadt transition temperature defined at 2 kg-m/cm². The more severe stress concentration of the Schnadt notch is reflected in the higher transition temperatures.

Charpy-V vs. Drop-weight Tests

To demonstrate a correlation between the drop-weight nil-ductility transition (NDT) temperature and service experience, the Naval Research Laboratory[12, 13, 18] has determined the NDT and Charpy-V transition temperatures of a group of rimmed and semikilled plain-carbon steels, including some casualty-ship steel. The intent was to establish a direct correlation between NDT and service-failure temperature for casualty steels, and an indirect correlation for non-casualty steels by showing that NDT intersected the Charpy curves at the same range of impact energies that correlated with service-failure temperatures in the NBC studies. At the NDT, the Charpy-V impact energy average 4.6 and 6.8 ft-lb for rimmed and semikilled steels, respectively. For these steels, NDT was interpreted by NRL as the highest temperature at which the steel *might* exhibit brittle fracture in service.

Charpy-V vs. Wide-plate Tests

This correlation[16, 17] includes rimmed, semikilled and fully killed plain-carbon steels, Fig. 7. Although wide-plate tests are customarily considered fracture-transition tests, it is possible, as in this instance, to define a transition temperature at a low level of absorbed energy, e.g., 20,000 in-lb. The arbitrariness of this definition illustrates well the empirical nature of the correlation between small notch-bar and larger full-plate-thickness tests.

Charpy-V vs. ESSO Tests[17, 19]

The ESSO Brittle and Charpy-V transition temperatures correlate reasonably well, Fig. 8. It is interesting that, for standard semikilled and rimmed steels, the Charpy-V 15 ft-lb temperature correlates, while for fully killed fine-grained steels the Charpy-V 30 ft-lb temperature is suitable.

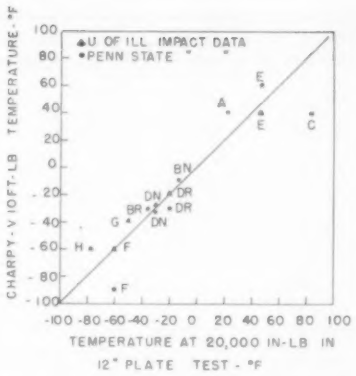

Fig. 7—Correlation between Charpy-V 10 ft-lb and 12-in.-wide-plate 20,000 in-lb transition temperatures for the project steels[16]

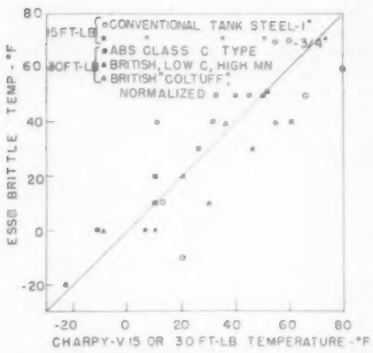

Fig. 8—Correlation between Charpy-V transition temperatures and ESSO brittle temperature[17]

Drop-weight vs. Kinzel Tests[19]

The drop-weight NDT and Kinzel 1% lateral-contraction temperatures show an acceptable correlation, Fig. 9, under conditions where the Kinzel-test transition is controlled by the ability of the base plate to arrest a cleavage crack. However, the correlation is destroyed when the Kinzel result is influenced by a notch-tough heat-affected zone.

Charpy-V vs. van der Veen Tests[20]

Although primarily a fracture-transition test, the van der Veen has been used as a ductility-transition test for comparison with the Charpy-V test. Both ductility and fracture transition temperatures are shown in Fig. 10 for eleven C-Mn steels. With few exceptions, the steels were rated in the same order by both tests. However, the authors state that with steels of greater differences in chemical composition and steelmaking practice, the correlation might be less exact.

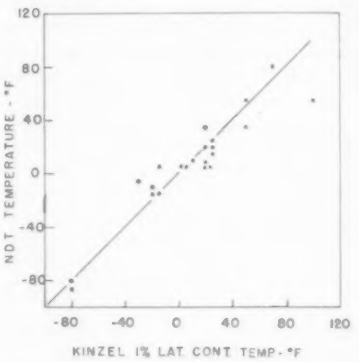

Fig. 9—Correlation between Kinzel 1% lateral contraction and NDT temperatures for a wide range of carbon and alloy steels[19]

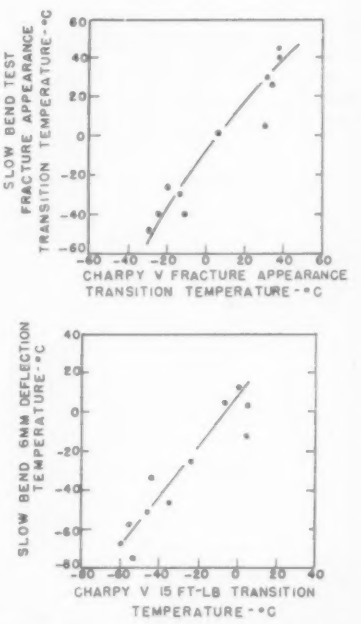
SLOW BEND TEST FRACTURE APPEARANCE TRANSITION TEMPERATURE - °C
CHARPY V FRACTURE APPEARANCE TRANSITION TEMPERATURE - °C
SLOW BEND 6MM DEFLECTION TEMPERATURE - °C
CHARPY V 15 FT-LB TRANSITION TEMPERATURE - °C

Fig. 10—Correlation of ductility and fracture transition temperature for the Charpy V and van der Veen slow notch bend tests[20]

Influence of Deoxidation Practice and Strength Level

It has been suggested[12, 13, 15, 21] that a Charpy-V 15 ft-lb temperature criterion is dangerously low for killed plain-carbon and low-alloy steels, and that correlation to service failure temperatures would be observed at higher foot pounds values. This conclusion was drawn from drop-weight tests, where NDT for fully killed steels fell at temperatures corresponding to Charpy-V 10–25 ft-lb with an average of 16.2 ft-lb, and for HTS steels at temperatures of 13–47 ft-lb with an average of 24.4 ft-lb, Fig. 11.

The Charpy-V drop-weight NDT "correlation shift" observed with these higher-quality steels results to a substantial degree from nor-

Table 1—Charpy-V ft-lb Values at the Nil-ductility Transition (NDT) Temperature for Various Steels in the As-rolled and Normalized Conditions[12,13]

Steel	Charpy-V ft-lb at NDT As-rolled	Normalized
3	13	47
4	6	19
40	17	17
41	11	18
42	11	16
43	10	15

Table 2—Charpy-V ft-lb Values at the Nil-ductility Transition (NDT) Temperature for a Range of Carbon and Alloy Steels[23]

	As-rolled		Annealed		Normalized	
Steel	NDT	ft-lb at NDT	NDT	ft-lb at NDT	NDT	ft-lb at NDT
A-201	+10	10	+30	7	0	13
A-285	...	9	+30	7	+20	8
A-212	+50	9	+50	8	+40	15
A-302	+20	13	−40	12	−30	13
A-302	+50	17	−20	12	−30	12
A-203	−60	8	−70	10	−100	23
HY-65	...	..	−70	8	−60	13
48s5	...	..	0	42	−10	45

malizing heat treatments, Table 1. For as-rolled fully killed steel, the highest Charpy-V value at NDT is 17 ft-lb, whereas for normalized steel it is 25 ft-lb. The HTS steel 3 shows this to a striking degree; in the as-rolled condition NDT occurs at a temperature of Charpy-V 13 ft-lb,[12] and in the normalized condition at a temperature of Charpy-V 47 ft-lb.[13] Recent Lehigh data,[22] Table 2, also indicate this effect.

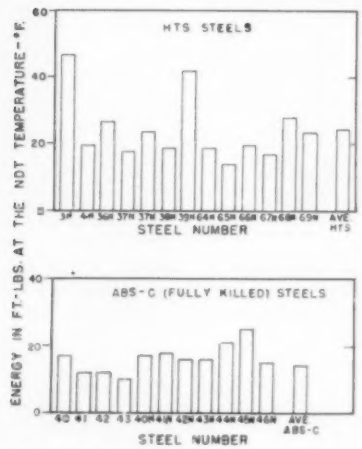
HTS STEELS
ENERGY IN FT-LBS. AT THE NDT TEMPERATURE - °F.
STEEL NUMBER
ABS-C (FULLY KILLED) STEELS
ENERGY IN FT-LBS. AT THE NDT TEMPERATURE - °F.
STEEL NUMBER

Fig. 11—Charpy-V ft-lb values at the NDT temperature for various steels[13]

This behavior seems to be reflected in the meager service data available,[21] where an annealed 3-in. thick A302 shell is reported as failing at a temperature of Charpy-V 8–9 ft-lb, while a normalized A302 vessel failed at a temperature of Charpy-V 18–20 ft-lb.

To attempt a resolution of this correlation shift, the available data were summarized,[19] Fig. 12. Although the scatter band is broad[24] there is no tendency for a given class of steels to segregate within the band, i.e., to fall exclusively in the upper or lower extremities of the scatter range.

The correlation is not ideal, however, since for steels of high notch toughness the Charpy-V transition temperature is lower than NDT, while the opposite is true for steels of poor notch toughness. Normalizing causes a similar effect, Fig. 13.[19, 22] With but one exception, normalizing decreases the Charpy-V 10 ft-lb temperature more than NDT.

To a great extent, this occurs because the Charpy and drop-weight tests measure different material characteristics.[24] The drop-weight test is a constant ductility test, since the criterion is whether or not the steel can display sufficient ductility to stop a running cleavage crack within an arbitrary low bend angle. On the other hand, impact energy in the Charpy test is influenced by both the strength and the ductility of the steel. This suggests that much of the "correlation shift" to higher Charpy-V values is due to the increased strength of alloy steels; i.e., the energy criterion for interpreting Charpy-V data must increase with increasing tensile strength to maintain a constant notch ductility. Normalizing, which may or may not alter strength, sometimes enhances this shift by decreasing the Charpy-V transition temperature more than NDT.

These concepts may be assessed when the Charpy-V test is evaluated as a constant-ductility test, Fig. 14. The 15-mil lateral-expansion criterion was selected since it correlates well with the NBS results and shows promise of correlation with NDT, Fig. 15. The slope of 0.94 results when both tests are judged by an appropriate level of ductility.

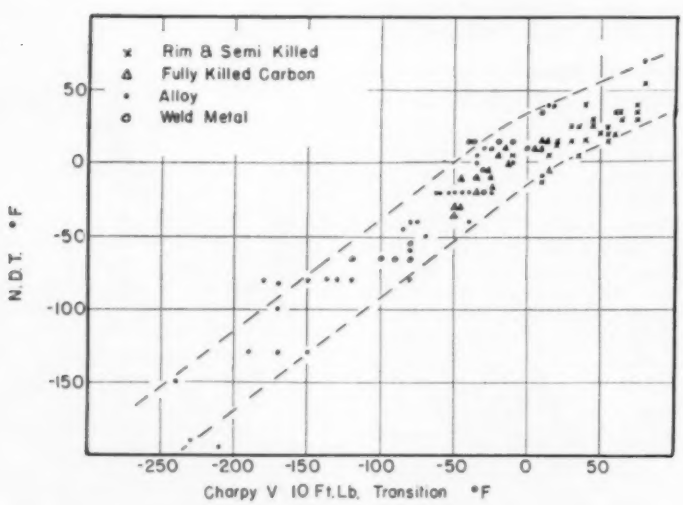

Fig. 12—Comparison of Charpy-V and drop-weight transition temperatures for carbon and low-alloy structural steels, 1-in. thick plates[19]

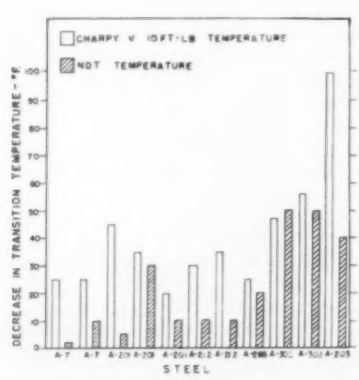

Fig. 13—Influence of normalizing upon Charpy-V and drop-weight transition temperatures[19, 22]

Table 3—Statistical Analyses of Influence of Chemical Composition upon Charpy-V Transition Temperature and Probability of Service Brittle Fracture[16]

A. Coefficients for calculation of Charpy-V 15 ft-lb trans. temp. numbers represent the coefficients by which the percentage of each element must be multiplied to find the change in transition temperature due to that element

	Method of computation		
	A	B	C
C	380	304	314
Mn	−68	−68	−87
P	314	332	308
Si	−297	−278	−271

B. Coefficients for discriminant functions

	Source vs. non-source[a]		End vs. nonend[b]	
	A	B	A	B
C	3.76	3.46	2.97	2.17
Mn	0.02	−0.004	−0.21	−0.17
P	12.2	12.7	2.3	2.2
Si	−4.77	−4.72	−1.50	−1.20

[a] Positive coefficients indicate factors that increase the probability that a plate will be in the source category.

[b] Positive coefficients indicate factors that increase the probability that a plate will be in the nonend category.

Table 4—Approximate Change in Transition Temperatures Produced by Various Elements

Element varied	Change in transition temperature, ° F: Tear test	10 ft-lb Charpy keyhole	15 ft-lb Charpy-V notch[24]	15 ft-lb Charpy-V notch[11]	Drop wt., NDT	Kinzel 1% lat. cont.	Esso britt temp.
0.1% C	+33	+20	+25	+35	+45	+50	+50
0.1% Mn	−4	−7	−10	−7.5	...	no effect	...
0.1% Si (0.2% max.)	−30	...	...	−28	...	...	...
0.1% Si (0.3% min.)	+15	...	+13	...	...	...	...
0.01% P	+5	...	+13	+3.2	no effect	+12	...

Influence of Chemical Composition

The NBS ship-fracture data have been analyzed statistically[11] to determine the influence of chemical composition upon brittle failure in service and upon the Charpy-V 15 ft-lb transition temperature. The conclusions Table 3, are valid only for the range of chemical compositions and mill practices represented by the ship-fracture steels.

Carbon increased both the susceptibility to service fracture and the Charpy 15 ft-lb temperature, the latter increasing about 35° F for each 0.1% carbon. The service data indicates that carbon enhanced crack initiation more than propagation, which the author suggests may be due to the adverse effect of carbon upon weldability. The insensitivity of service failure behavior to Mn content suggests that the often reported[3, 6] beneficial effect of Mn may result from its strengthening influence, which allows a lower carbon content with no decrease in strength level.

Phosphorus strongly increased susceptibility to service failure and, particularly, fracture initiation. Welded plates show a strong correlation between phosphorus content and notch toughness as measured by the Kinzel test.[25] Silicon (0.00–0.12%) was beneficial; but the author remarks that other investigators have found an increase in transition temperature when the silicon content exceeds 0.25%. A possible explanation is that silicon acts primarily as a deoxidizer at low concentrations, but also as an alloying element at higher concentrations.

The influence of chemical composition upon transition temperatures as measured by different laboratory tests is summarized in Table 4, compiled from the literature.[3] The Charpy-keyhole and tear-test data were obtained with laboratory heats of semikilled plain-carbon steels,[26] and the Charpy-V data with laboratory heats of fully deoxidized steels.[27] All tests show a substantial adverse influence of carbon. The available data indicate that the drop-weight test does not confirm the effect of phosphorus shown by the NBS analysis. In general, however, the different tests are remarkably similar in responses to changes in chemical composition. Except for manganese and, possibly, phosphorus, the results correlate well with the NBS analysis of ship-fracture data.

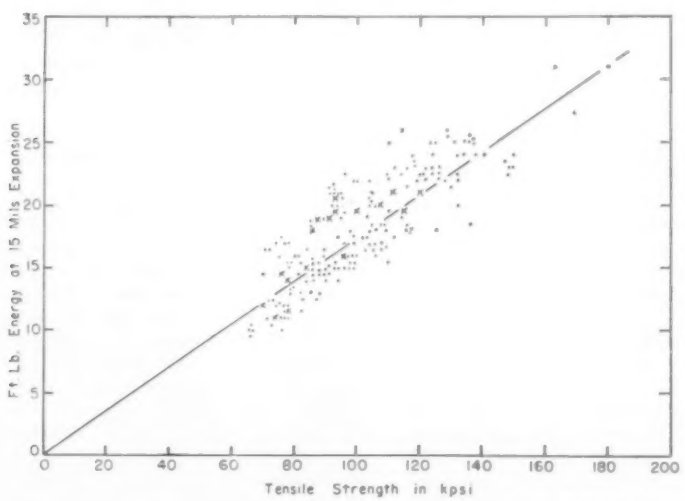

Fig. 14—Increase in energy absorption with tensile strength at a constant lateral expansion of 15 mils for a variety of steels and heat treatments[22]

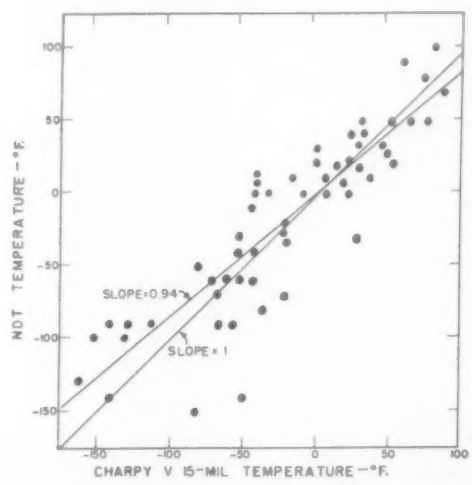

Fig. 15—Comparison of Charpy-V 15-mil and NDT temperatures for a range of steels and pretest treatments[22]

Table 5—Effect of Postheat on Drop-weight Nil-ductility, Transition (NDT) Temperature, ° F

Steel	Condition	Standard NDT temp., ° F	Postheated NDT temp., ° F
T-1	Q & T	−80	−90
A-302	AR	+55	−50
A-212	AR	+15	+20
A-7	AR	+35	+45
A-7	AR	+ 5	+15

Influence of Plate Thickness and Grain Size

The NBS statistical analysis of ship fracture steels[11] shows that an increase in plate thickness from 0.5 to 1.5 in. does not increase susceptibility to brittle failure in service, but is associated with increased grain size and Charpy-V transition temperatures.

In accord with the NBS service data, the NDT is reported[28] to be independent of thickness when a specified normalization procedure is used. This consists of appropriate combinations of span and stop distance which are reported to yield constant surface strains and NDT values for varying specimen thicknesses. However, in tests where only the stop distance was varied to induce constant plastic strain in the specimen surface, NDT increased with increasing thickness.[29, 30] Most laboratory tests show an increase in transition temperature with plate thickness.[1]

Summary Discussion

In general, the different tests concur in describing the effects of composition, deoxidation practice, grain-size, etc. However, this agreement is statistical rather than exact, and occasionally excessive scatter or even contradictory results are obtained. Thus, the broad correlations observed among tests are of little use to a design engineer faced with the task of selecting a specific steel for a specific application.

In view of this, it is desirable to discuss further those tests which are considered particularly relevant to the behavior of welded structures and which are in reasonably widespread use. These are the drop-weight, Charpy-V and Kinzel tests.

Table 6—Effect of Cooling Rate on the Nil-ductility Transition (NDT) Temperature[29]

	Split and welded		Welded and split	
Steel	NDT, ° F	Weld-metal hardness, VHN	NDT	Weld-metal hardness, VHN
A-201	−50	333	−40	437
A-212	0	421	−20	459
A-302	−30	339	−80	405
A-302	−30	380	−30	413
A-203	−100	354	−90	390
T-1	−170	342	−120	401

Drop-weight Test

This test is intended to measure the highest temperature at which a given steel might exhibit brittle fracture when fabricated into a service structure. The test conditions are deemed representative of the most severe conditions encountered in service,[12, 15] with the running cleavage crack simulating design or fabrication notches and the rapid loading system simulating the elastic energy in large welded structures.

It must be realized that failure is not inevitable if the service temperature is below NDT, but that brittle fracture is a possibility. Whether or not failure will actually occur depends upon factors which notch-toughness tests cannot evaluate, e.g., structure design, fabrication procedure and nature of service loading. Undoubtedly, many structures are in use today at temperatures below NDT. Whether or not the NDT concept should be applied to a specific structure is a matter for sound engineering judgment.

For rimmed and semikilled steels, the NDT concept is based upon a statistical correlation with the NBS investigations and with limited ship-fracture data. Briefly, the NBS established that ship-fracture source plates failed at temperatures corresponding to an average Charpy-V value of 7.4 ft-lb, while drop-weight tests on a few ship-fracture steels and many similar steels showed that NDT occurred at temperatures corresponding to an average Charpy-V value of 5.9 ft-lb. The correlation is good, but the lower Charpy-V value at NDT means that the average NDT is less than the average service-failure temperature. Thus, for this class of steels, the NDT does not provide a margin of safety and will occasionally be lower than the service-failure temperature.

For fully killed and low-alloy steels, there is no extensive body of service-failure data but, in the few cases investigated, the service-failure temperature has invariably been below NDT. Of particular interest is the occurrence of two failures at temperatures corresponding to Charpy-V values from 17 to 20 ft-lb.

The drop-weight test is a base-plate test;[12] the NDT is considered to represent base-plate properties exclusively, and not to be influenced by the thermal cycle necessary for depositing the hard-surfacing bead. However, it is of interest to discuss the role of the heat-affected zone (HAZ), since the cleavage crack must traverse this region before entering the base plate. If the heat-affected zone is equally or more notch sensitive than the base plate, then the crack will propagate unhindered through the heat-affected zone, and NDT will represent base-plate properties. This is probably the case with the majority of steels.

On the other hand, if one or more of the heat-affected zone microstructures are highly notch tough, then that zone may interrupt the propagation of the cleavage crack and cause a spuriously low NDT. Although uncommon, this does occur in a few situations. For example, recently[21] it was found that the heat-affected zone might influence the NDT temperature of low-alloy steels (A203, A302) when tested in the as-rolled and in the normalized condition. The fracture surfaces of broken drop-weight specimens displayed fibrous or shear rings in the heat-affected zone. These rings indicated an interruption of cleavage crack propagation, and that the measured NDT was probably lower than the true base-plate NDT.

Postheating may occasionally produce a notch-tough structure in the heat-affected zone with a concomitant lowering of NDT,[19] Table 5. Of the steels tested, only A302 shows a decrease in NDT; this resulted from a tough-tempered low-carbon martensite structure in the heat-affected zone.

In another investigation,[29] the influence of the heat-affected zone upon the NDT temperature of a range of carbon and low-alloy steels was studied. The experimental procedure was to compare the NDT temperatures of specimens welded as 1-in. plate and then split to $^1/_2$ in. and tested, with the NDT temperatures of specimens split to $^1/_2$ in. thickness and then welded and tested. The welded and split specimens exhibited a significantly smaller heat-affected zone because of the faster cooling rate. The results, Table 6, indicate an influence on NDT for some steels (A212, A302) whose heat-affected zone micro-

structures are sensitive to the range of cooling rates employed.

Anomalous NDT results have been observed with strained and aged steels;[22] Fig. 16; A203 shows this to a striking degree. A 5% prestrain *decreased* the NDT to −150° F from the normalized and stress-relieved value of −90° F. A 2-hr aging at 500° F subsequent to prestraining resulted in an NDT of −140° F. On the other hand, the Charpy-V 15-mil lateral-expansion temperature was *increased* 44° F by prestraining and 80° F by prestraining and aging, as would normally be expected. Thus, the NDT does not invariably represent base-plate properties.

Pellini and Puzak[23] have noted drop-weight specimens of quenched or quenched-and-tempered steels should be prepared by hardening the specimens after depositing the crack-starting weld metal. However, this procedure limits the tempering temperature to less than 600° F, since higher temperatures soften the hard-surfacing bead and alter its crack-starting characteristics. They have also cautioned against drop-weight tests on plastically deformed steel because of possible recrystallization of ferrite in the heat-affected zone. However, the fact remains that quenched or quenched-and-tempered steels, as well as cold-formed steels, are fabricated by welding, and an assessment of the brittle-fracture susceptibility of the composite structure is necessary.

In summary, the drop-weight test furnishes valuable information for preventing brittle fracture in welded structures. With due regard for the isolated situations where tough heat-affected zone structures may influence the results, the NDT temperature correlates well with service experience, and seems representative of base-plate susceptibility to brittle fracture. For critical applications, the drop-weight test seems an appropriate guide to service behavior of prospective steels. For less critical applications, the NDT philosophy is unduly conservative, since it assumes the existence of crack-like defects at critical locations. However, it must be remembered that neither the drop-weight test nor any other notch-toughness test can measure the transition temperature of a specific engineering structure.

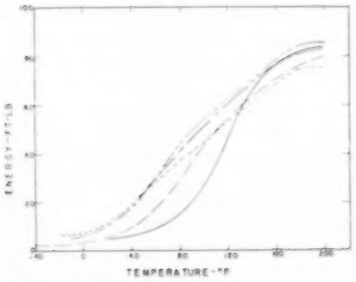

Fig. 16—Various Charpy-V energy curves reported for project C steel[22]

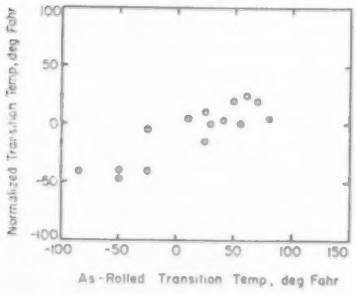

Fig. 17—Influence of normalizing upon transition temperatures of carbon and alloy steels in the Kinzel test; 1-in-thick plates, welded at 180 amp, 10 ipm travel speed[25]

The Kinzel Test

This test is modest in intent, since it does not purport to show a direct correlation with service, but it does give valuable information on the relative merits of steel compositions, of heat treatments before and after welding and of welding procedures. The Kinzel test thus measures the effect of welding upon the base metal. Because of grain coarsening, partial hardening and, perhaps, plastic flow, the heat-affected zone is usually, although not invariably, more notch sensitive than the unaffected base plate. Considerable influence upon this embrittlement is exerted by welding current, travel speed, preheat temperature and postheat treatment.

The influences of these factors and of normalizing are shown in Figs. 17 and 18. Postheating causes substantial improvement with all steels. Only the high-carbon steel is noticeably embrittled by the fast cooling rates accompanying low heat inputs. Normalizing usually improves as-rolled plate; quenching and tempering allows still further improvement, even in nonhardenable carbon steels. Tempering after quenching is essential for improvement.[32]

Interpretation of these results has been facilitated by analyses of the fracture surfaces of Kinzel specimens, coupled with a knowledge of the heat-affected-zone. In carbon steels, the coarse-grained area is the chief source of cleavage failure, since the aggregates of hard pearlite and/or martensite enveloped in weak ferrite are highly notch sensitive. In low-alloy steels (48s5, A203, A302, etc.), welding may produce all martensite coarse grains which are notch tough, and cleavage then initiates in the intercritical zone. Upon postheating, however, cleavage initiation reverts to the coarse-grained area.[25]

A broad picture of the fracture behavior of Kinzel specimens can be attempted as follows. In the absence of welding, the specimen fails at a level of 1% lateral contraction only at relatively low temperatures, low enough to favor early cleavage initiation from the shear crack which always forms first. Welding raises the transition temperature by creating zones in its vicinity that more readily generate cleavage cracking. The resulting transition will be located at the highest temperature at which an area of the weld can initiate a cleavage crack, which in turn cannot be arrested by the base metal—or by the refined-grain region when it is in a position to act. Thus, two requirements must be met to have brittle failure (less than 1% lateral contraction) in the Kinzel test. The temperature must be low enough to permit some zone to trigger cleavage, and it must be low enough to have the remaining steel section accept the cleavage crack. If this is so, the performance of welded steel can be improved by

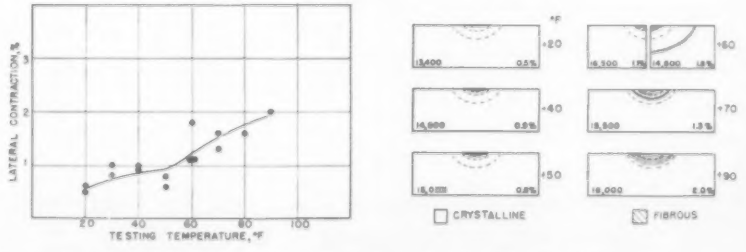

Fig. 18—Transition behavior and fracture patterns in Kinzel tests of 1-in. A285 steel welded with E6010 at 180 amp, 10 ipm[25]

Table 7—Comparison of Service-failure Temperatures with Different Transition Temperatures[21]

Correlation case no.	Service-failure temp., ° F	Charpy-V 15 ft-lb temp., ° F	NDT temp., ° F	Charpy-V 15% shear temp., ° F	Charpy-V 15 mil temp., ° F
1. Plain C steel	35	70	50	60	...
2. Plain C steel	5	50	30	30	30
3. 1¼ in. A285 Gr. C	45	75	60	60	90
4. 1¼ in. A212 Gr. B	65	120	80	90	90
5. 1¾ in. A204	45	160	110	90	130
6. 3 in. A302	60	90	70	85	90
7. 2⁹/₁₆ in. A302	70	40	100	80	40
8. 7⅝ in. A293	70	50	130	80	60
9. 83 in. A293	200	...	...	...	...
10. 1½ in. SAE 1050	70	175	100	150	140
11. SAE 3335	115	270	180	...	...
12. A293	70	400	400	370	450

toughening either the critical weld zone or the base plate. Postheating acts on the weld zone, while normalizing before welding affects mainly the base plate. Preheating and heat input to the weld can influence transition temperature only by their action on the triggering zone. Since they may alter its microstructure favorably or unfavorably according to the steel, it is not surprising to find them unreliable as a means of improving notch toughness.

The Charpy-V Test

The Charpy-V test is a versatile and widely used tool for investigating notch toughness. To a considerable extent this is so because the extensive NBS studies have established an accurate, if statistical, correlation between Charpy-V results and service behavior for rimmed and semikilled steels. Since ship failures were found to occur at temperatures corresponding to Charpy-V values from about 3 to 12 ft-lb in source plates, it became not uncommon to ask that structural steels exhibit 15 ft-lb at the expected minimum service temperature.

With increased use and testing of fully killed and low-alloy steels, however, it became apparent that 15 ft-lb was not sufficient for that class of structural steels. In that connection, it is of interest to review the available service data[21] with regard to correlation with various measures of the transition temperature. This summary is presented in Table 7, where the drop-weight NDT, the Charpy-V 15 ft-lb, 15-mil lateral expansion and 15% shear-fracture temperatures are compared with the service-failure temperatures. The two criteria exhibiting the best agreement with service are the drop-weight NDT and the 15% shear-fracture temperatures. In all cases, these two transition temperatures are above the service-failure temperature, and usually by about the same temperature differential. Thus, although the data are quite limited, it is evident that transition temperatures other than the NDT temperature will probably correlate with service.

The NBS data have also been analyzed to show that, under restricted conditions, a correlation may exist between the fracture and ductility transition temperatures.[22] The Charpy-V data for rimmed and semikilled steels indicate a good statistical correlation between the Charpy-V 15 ft-lb temperature and both the 50 and 10% shear-fracture temperatures, Fig. 19. The nature of this correlation would be expected to vary with class of steel, as is evident from the following data on the percent cleavage fracture at the Charpy-V 15 ft-lb temperature.

Ship-fracture steels, %	71
ABS-B steels, %	82.7
ABS-C steels, %	89.8

The observed correlation of Charpy-V test results with service behavior of welded structures is deserving of further comment. In welded structures of rimmed and semikilled plain-carbon steels, the base-plate properties control fracture behavior. This is because crack initiation in the heat-affected zone, from either mechanical or metallurgical notches, is relatively simple, since the heat-affected-zone structures are invariably more notch sensitive than the base plate. Furthermore, the heat-affected zone is rather insensitive to welding conditions for these steels. The important question is whether or not the brittle crack can enter into and propagate through the base plate. Thus, a base-plate test, such as the Charpy V, should correlate with the service behavior of rimmed and semikilled steel structures.

For alloy steels, the factors controlling brittle fracture in welded structures are less certain. With these steels, notch-tough microstructures may be formed in the heat-affected zone, and they will probably influence initiation behavior. Moreover, the weld metal may be less tough than the base plate, whereas it is usually tougher than carbon-steel base plate. Thus, for these steels, base-plate tests may not always correlate with service behavior. Unfortunately,

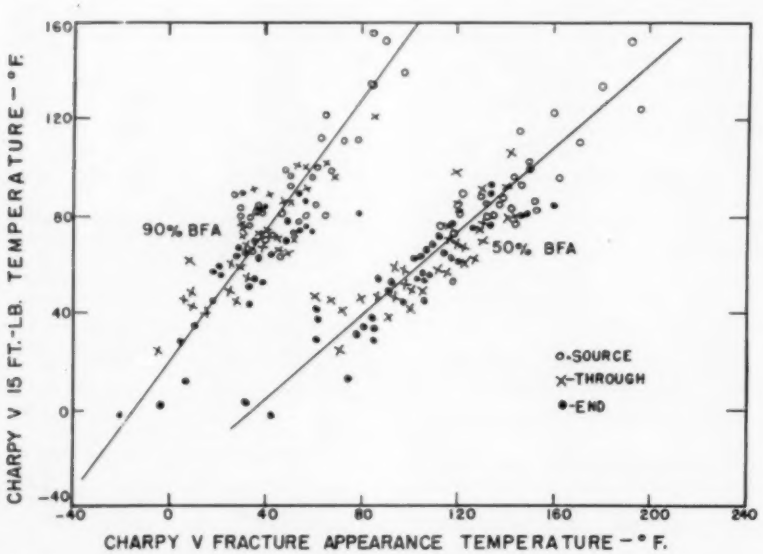

Fig. 19—Comparison of Charpy-V 15 ft-lb temperatures with the temperatures of 50% and 90% brittle fracture appearance.[23]

service information on this point is extremely limited.

Conclusions

From an extensive survey of the literature on notch-toughness tests and from consideration of recent test results obtained in this laboratory, the following conclusions are felt to be warranted:

1. The most important conclusion obtained from this study is that there is no single notch-toughness test which can predict the transition temperature of a specific structure, for that temperature depends at least partially upon factors which notch-toughness tests are inherently unable to evaluate, such as structure design and fabrication procedures.

2. When tests measuring ductility transition temperatures are used to evaluate base-plate properties, a statistical correlation is obtained; e.g., correlation among the Charpy-V, drop-weight and Kinzel tests will exist when the last two tests are evaluating base-plate susceptibility to brittle fracture. If conditions are such that notch tough heat-affected-zone microstructures are produced in Kinzel or drop-weight specimens, then wide deviations from correlation may be observed.

3. From the ship fracture studies of the NBS, a correlation between the Charpy-V 15 ft-lb ductility transition temperature and the 50% shear-fracture transition temperature has been demonstrated, with a separation of about 40° F.

4. The correlation between the Charpy-V 10 ft-lb transition and the NDT temperatures is not one-to-one; for steels of low notch toughness (rimmed and semikilled steels), the NDT temperature is usually lower than the 10 ft-lb temperature, while for steels of high notch toughness (fully killed and alloy steels), the NDT temperature is considerably higher than the 10 ft-lb temperature. This disparity is almost completely removed when the Charpy-V test is evaluated as a ductility test and the 15-mil lateral-expension temperature is plotted against the NDT temperature. The correlation is nearly one-to-one.

5. Normalizing lowers the Charpy-V 15 ft-lb transition temperature much more than the NDT temperature, and it also lowers the Kinzel 1% lateral-contraction temperature.

6. To a surprising degree, the different tests agree in their evaluation of the influence of chemical composition upon notch toughness. Furthermore, except for manganese, and in some cases phosphorus, the test results are in accord with service behavior for ship-fracture steels.

7. The drop-weight test may be adjusted to be independent of section size, but the other tests studied indicate poorer notch toughness with thick sections largely because of metallurgical effects.

8. The Charpy-V and drop-weight tests supply valuable information with respect to base-plate properties and brittle fracture in welded structures. For rimmed and semikilled steels, a statistical analysis has established that a Charpy-V value of 15 ft-lb at the lowest service temperature is satisfactory.

9. For fully killed and low-alloy steels service experience has shown that a higher Charpy-V ft-lb criterion would be necessary. The NDT temperature correlates with service experience for these steels in the sense that it has always occurred above the service-failure temperature. However, the Charpy-V 15% shear-fracture transition temperature is equally satisfactory in this respect. For rimmed and semikilled steels, the NDT temperature may not provide an adequate margin of safety.

10. The Kinzel test provides useful information on the relative merits of steel compositions, of heat treatments before and after welding and welding procedures. A correlation with the NDT temperature results when the Kinzel test is evaluating the base-plate resistance to brittle fracture. The correlation is destroyed if notch-tough microstructures are present in the heat-affected zone of the Kinzel specimen.

Acknowledgments

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Bibliography

1. Johnson, H. H., and Stout, R. D., *Comparison and Analysis of Notch Toughness Tests for Steels in Welded Structures*, Welding Research Council, Bull. No. 62, July 1960.

2. Report of Subcommission A, Commission IX, Document No. IX—144–158, International Institute of Welding.

3. Parker, Earl R., *Brittle Behavior of Engineering Structures*, John Wiley & Sons, New York (1957).

4. Stout, R. D., and Doty, W. D., *Weldability of Steels*, Welding Research Council, New York (1953).

5. ASTM Tech. Pub. No. 158, "Brittle Behavior of Metals with Particular Reference to Low Temperatures," ASTM (1953).

6. Plasticity Committee, *Control of Steel Construction to Avoid Brittle Failure*, Welding Research Council, New York (1957).

7. Pellini, W. S., "Evaluation of the Significance of Charpy Tests," ASTM Tech. Pub. No. 158, Brittle Behavior of Metals with Particular Reference to Low Temperatures, ASTM (1953).

8. Kahn, N. A., and Imbembo, E. A., "A Method of Evaluating Transition from Shear to Cleavage Failure in Ship Plate and its Correlation with Large-Scale Plate Tests," THE WELDING JOURNAL, **27** (4), Research Suppl., 169-s to 182-s (1948).

9. Stout, R. D., and McGeady, L. J., "The Meaning and Measurement of Transition Temperature," *Ibid.*, **27** (16), Research Suppl., pp. 229-s to 302-s (1948).

10. Williams, M. L., "Analysis of Brittle Behavior in Ship Plate," ASTM Spec. Tech. Pub. No. 158, 1953 on Brittle Behavior of Metals at Low Temperatures.

11. Williams, M. L., "Correlation of Metallurgical Properties and Service Performance of Steel Plates from Fractured Ships," THE WELDING JOURNAL, **37** (10), Research Suppl., 445-s to 453-s (1958).

12. Puzak, P. P., Eschbacher, E. W., and Pellini, W. S., "Initiation and Propagation of Brittle Fracture in Structural Steels," *Ibid.*, **31** (12), Research Suppl., 561-s to 581-s (1952).

13. Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Applicability of Charpy Test Data," *Ibid.*, **33** (9), Research Suppl., 443-s (1954).

14. Discussion by Henry M. Schnadt, "On Notch Brittleness Tests Employing a Notched Weld," *Ibid.*, **36** (1), Research Suppl., 8-s (1957).

15. Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Crack Starter Tests of Ship Fracture and Project Steels," *Ibid.*, **33** (10), Research Suppl., 481-s (1954).

16. Vanderbeck, R. W., and Gensamer, M., "Evaluating Notch Toughness," *Ibid.*, **29** (7), Research Suppl., 37-s (1950).

17. Feely, F. J., Jr., Northup, M. D., Kleppe, S. R., and Gensamer, M., "Studies on the Brittle Failure of Tankage Steel Plates," *Ibid.*, **34** (12), Research Suppl., 608-s to 617-s (1955).

18. Feely, F. J., Jr., Hrtko, D., Kleppe, S. R., and Northup, M. S., "Report on Brittle Fracture Studies," *Ibid.*, **33** (2), Research Suppl., 99-s to 111-s (1954).

19. Murphy, W. J., McMullen, W. D., and Stout, R. D., "Relative Behavior of Notch-Toughness Tests for Welded Steel," *Ibid.*, **36** (6), Research Suppl., 307-s to 311-s (1957).

20. I.I.W. Report, "Comparison of Slow Notch Bend Test and V-Notch Charpy Impact Test," *Ibid.*, **34** (7), Research Suppl., 338-s to 347-s (1955).

21. Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Correlations of Brittle-Fracture Service Failures with Laboratory Notch-Ductility Tests," *Ibid.*, **37** (9), Research Suppl., 391-s to 410-s (1958).

22. Gross, J. H., "A Comparison of the Charpy-V Notch and Drop Weight Tests for Structural Steels," Presented at the AWS Annual Meeting, Detroit (1959).

23. Pellini, W. S., and Puzak, P. P., Discussion to Reference 19, THE WELDING JOURNAL, **36** (11), Research Suppl., 511-s (1957).

24. Gross, J. H. and Stout, R. D., "Ductility and Energy Relations in Charpy Tests of Structural Steels," *Ibid.*, **37** (4), Research Suppl., 151-s to 158-s (1958).

25. Stout, R. D., "Weldability Tests as a Guide to Service Performance of Weldments," Presented at Chicago Regional Technical Meeting of American Iron and Steel Institute (October 22, 1958).

26. Banta, H. M., Frazier, R. H., and Lorig, O. H., "Some Metallurgical Aspects of Ship Steel Quality," THE WELDING JOURNAL, **30** (2), Research Suppl., 79-s to 90-s (1951).

27. Rinebolt, J. A., and Harris, W. J., Jr., "Effect of Alloying Elements on Notch Toughness of Pearlitic Steels," Trans. ASM 43, 1175–1214 (1951).

28. Puzak, P. P., and Babecki, A. J., "Normalization Procedures for WRL Drop Weight Test," THE WELDING JOURNAL, **38** (5), Research Suppl., 209-s (1959).

29. Mittelman, M. D., Master's Thesis submitted to Lehigh University, "Survey of the Test Variables of the Drop Weight Test," (1959).

30. R. E. Somers, private communication.

31. Agnew, S. A., Master's Thesis submitted to Lehigh University, "Response of the Kinzel Test to Metallurgical and Geometrical Variations," (1959).

32. Gross, J. H., Kottcamp, E. H., and Stout, R. D., "Effect of Heat Treatment on the Microstructure and Low-Temperature Properties of Pressure Vessel Steels," THE WELDING JOURNAL, **37** (4), Research Suppl., 160-s to 167-s (1958).

33. Bennett, J. A., "Fracture Appearance of Impact Specimens Taken from Fractured Ship Plates," Ship Structure Committee Report No. 113 (1959).

Properties of Chromium-Steel Weld Metal

The effect of temperature upon the tensile, hardness and microstructure characteristics of chromium steel welds is described and data are applicable to design and service needs

BY J. HEUSCHKEL

Introduction

Chromium steels, nominally Fe-Cr-C alloys, are used for applications requiring corrosion resistance, and for strength at intermediate temperatures.[1] They are used in welded structures to a limited extent. Most industrial welding experience has been secured with the covered electrode, shielded, metal-arc process.[2] This report describes the effect of temperature upon the tensile, hardness and microstructure characteristics of such welds. The data are applicable to design and service needs and they provide a background from which to judge the properties of other welds containing chromium.

The influences of temperature and composition upon the mechanical properties are clearly illustrated by superimposing the values obtained for different compositions and test temperatures upon the established Fe-Cr equilibrium diagram.[3] Welds containing more than 12% Cr, which do not undergo an alpha-gamma-alpha transformation upon heating and cooling, are very ductile at high temperatures, while the lower-chromium-content welds that do undergo such a transformation are only nominally ductile within the gamma loop, but all compositions containing more than 12% Cr are brittle at room temperature; i.e., they exhibit less than 12% elongation and area reduction. They are so brittle that they have low strength, due to the occurrence of rupture on the rising portion of the load-strain curve.

Test Procedure

For convenience, 0 to 25% Cr-content welds were made between "pre-buttered" V-grooved edges of unrestrained 3/4 x 4 x 18-in. plain-carbon steel plates, using commercially available covered electrodes to secure, most readily, six levels of chromium content, Table 1. The metal temperature was 200° F at the start of each deposited bead. All welds were found to be sound, as judged from X-ray and macrographic examinations. Tensile tests were then made at a constant strain rate of 750% per hr on smooth bar, 0.357 in. diam, all-weld-metal specimens, containing nominally 0, 5, 13, 15, 17 and 25% Cr, across the temperature range between −320 and +2000°F. The longitudinal axes of the test specimens were coincident with the central axes of the welds. Also, for the 5, 13, and 15% Cr-content welds, such tests were made at room temperature after the heat treatments listed in Table 2. The data secured provide a basis for describing the influence of chromium, within the range from 0 to 25%, upon weld-metal characteristics.

Hardness impressions were made on an end of each tensile specimen, after rupture, to determine the influence of brief exposures to each of the test temperatures when followed by slow cooling.

Micrographs were made of the weld-metal structures in the as-deposited condition, and after brief exposures within the 1200 to 2000° F test-temperature range.

Check analyses were made from the shanks of room-temperature tensile specimens for each weld series after testing. These analyses are averages, typical of the metal tested.

Detail results, secured from the tensile tests, chemical analyses and hardness impressions, are shown in Tables 1 and 2 and in Figs. 1 to 9, inclusive. Some corresponding microstructures are shown in Figs. 10 and 11.

Discussion

Temperature Dependence of Tensile Properties

The temperature dependence of the tensile properties of covered-electrode, carbon-steel weld metals

Table 1—Chemical Compositions of Weld Metals (Weight %)

	Sample Mark					
Element	CR-O	CR-4	CR-12	CR-16	41	42
Cr	0.00	5.41	12.7	14.6	17.4	25.1
C	0.10	0.062	0.069	0.061	0.040	0.040
Mn	0.59	0.62	0.48	0.48	0.81	0.78
P	0.016	0.011	0.024	0.026	0.020	0.025
S	0.025	0.010	0.013	0.017	0.019	0.014
Si	0.18	0.40	0.39	0.22	0.71	0.70
Cu	...	0.11	0.10	0.086	0.12	0.12
Ni	...	0.08	0.21	0.27	0.25	0.51
Mo	...	0.52	0.29	0.036	0.058	0.029
V	...	0.03	0.03	0.06	0.048	0.24
Ti	...	0.02	0.01	0.02	0.024	<0.005
Nb + Ta	...	<0.04	<0.04	<0.04	...	...
Al	...	0.036	0.037	0.040	...	...
N	0.007	0.023	0.028	0.037	0.037	0.11
O	...	0.049	0.046	0.112	...	.....

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was reported in earlier papers.[4,5] As-deposited weld metal containing 5.4% Cr and 0.52% Mo tends to follow the same general temperature-dependence pattern as low-carbon steel, with higher strength and lower ductility (see Fig. 1). With increased temperature, there was a ductility dip at 600° F and another at 1800° F. The first occurred in a region of precipitation hardening and the second as the alpha-to-gamma phase transformation temperature was reached. Upon subcooling, the ductility remained about constant down to −100° F, but approached zero at −320° F, the liquid-nitrogen temperature.

The 12.7% Cr-content weld responded in a similar manner, but the stress and ductility values were lower. The strength at 2000° F was very low. The ductility was low for all temperatures at and below 600° F, and there was a lowered value at 1800° F. The ductility was excellent at 1200 and 1500° F, the area reduction being more than 80%.

The 14.6% Cr-content weld, Fig. 2, exhibited no rise in stress as temperatures were reduced below 600° F; instead, from 600° F downward, there was a decrease in strength with decreasing temperature as failure occurred on the rising-load portion of the load–strain curves due to the low ductilities achieved at and below 600° F. There is a significant dip in ductility at 1800° F but, again, excellent ductility was secured between 1200 and 1500° F.

The 17.4% Cr-content weld also decreased in strength as temperatures were reduced below 500° F, again because rupture occurred on the rising portion of the load–strain curve. It had low ductility for all temperatures less than 500° F, but excellent ductility for all test temperatures above 1000° F.

The 25.1% Cr-content weld had

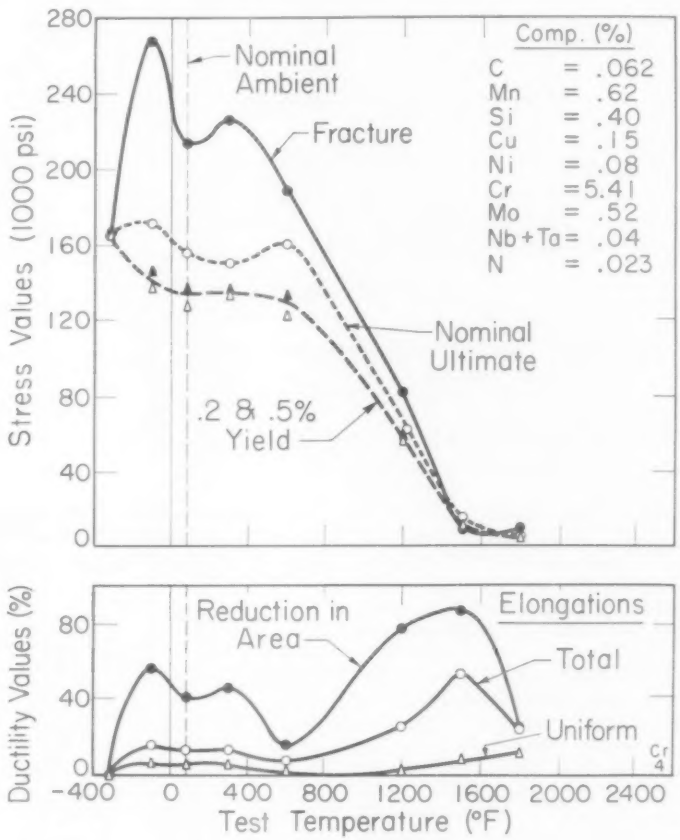


Fig. 1—Tensile values for 5.4% Cr steel weld metal

Table 2—Unnotched Tensile Properties at +80° F

Chromium content, %	Nominal strength, psi (appropriate load/original area) 0.2% yield	0.5% yield	Ultimate	True stress at fracture, psi (final load)/(final area)	Elongation, % Uniform	Total	Area reduction, %	Butt-end hardness after testing, DPH
"As-deposited"								
0.0	55,020	53,200	64,620	132,200	19.11	36.06	63.62	149
5.4	128,600	137,650	155,900	213,900	4.76	11.82	39.18	351
12.7	104,000	112,200	112,200	136,200	5.0	5.0	6.5	304
14.6	71,750	79,550	79,550	101,000	3.0	3.0	4.7	247
17.4	64,800	74,700	79,000	79,000	2.0	2.0	2.1	260
25.1	61,900	63,750	84,150	84,150	12.4	12.4	12.2	233
Heated 1100° F, 1 hr—furnace cool to 500° F								
5.4	126,600	130,400	137,600	223,500	3.98	15.47	60.20	325
12.7	87,000	91,800	108,600	164,500	6.88	15.04	45.30	253
14.6	67,060	73,080	90,550	131,000	8.67	16.29	39.18	232
Heated 1500° F, 24 hr—ice water quench								
5.4	137,800	150,400	165,400	228,800	4.47	11.93	39.15	363
12.7	78,350	87,380	111,600	147,900	10.17	16.88	29.66	276
14.6	55,000	62,400	86,000	124,600	9.55	15.19	35.8	199
Heated 1800° F, 1 hr—ice water quench								
5.4	140,250	152,650	167,300	245,200	3.26	13.10	52.00	342
12.7	122,700	166,800	...	205,500	...	4.98	9.3	373
14.6	102,300	113,800	...	128,000	...	1.28	2.49	330

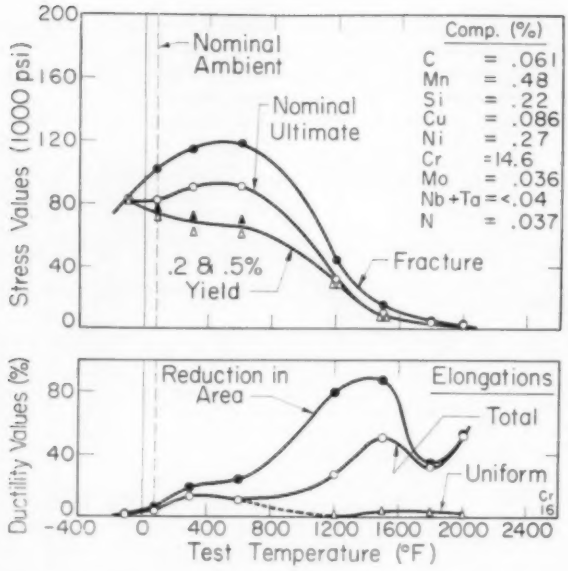


Fig. 2—Tensile values for 14.6% Cr steel weld metal

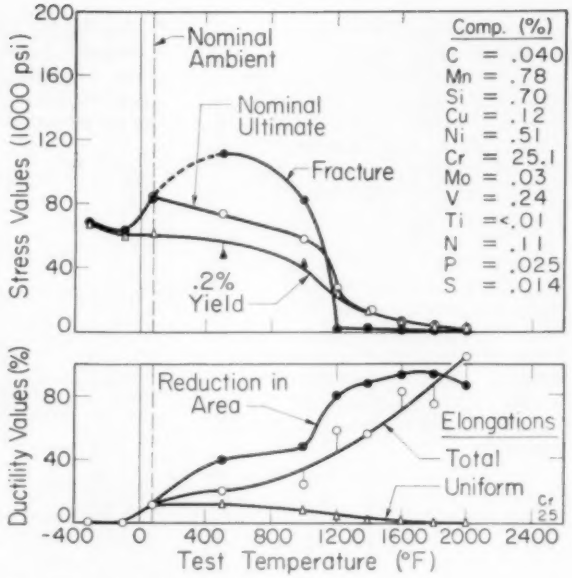


Fig. 3—Tensile values for 25% Cr steel weld metal

tensile properties similar to the one with 17.4% Cr. The ductility increased progressively as temperature increased and the strengths decreased, except that the fracture stress was a maximum at 500° F, Fig. 3.

The stress–ductility characteristics are more readily understood by reviewing the shape of the individual specimen load–strain curves. When a cylindrical specimen is elastically strained in tension, the length–diameter changes are inversely uniform. Under plastic strain the same relative conditions apply, up to the attainment of maximum load. The volume of metal remains constant. After the maximum load is reached, for ductile metals the area reduction starts to become nonuniform, that is, localized. The values of "uniform elongation," Figs. 1 to 3, describe the strain level at which this change in flow mechanism occurs. For temperatures above which cold working occurs, 1200° F and over, the magnitude of the uniform strain is usually very low, less than 10%. Low magnitudes of "uniform elongation" at high temperatures, as low as 1%, do not necessarily imply brittleness; rather, only the absence of a capacity for cold work. In general, unalloyed ferritic low-carbon steel welds do not work harden above 1400° F.[4]

Composition Dependence of Tensile Properties

The manner by which composition affects weld strength and ductility is conveniently shown by superimposing the temperature–ductility–strength values upon the Cr-Fe equilibrium diagram. Total elongation is a minimum for the lower temperatures above the 2% Cr range, Fig. 4. It is better

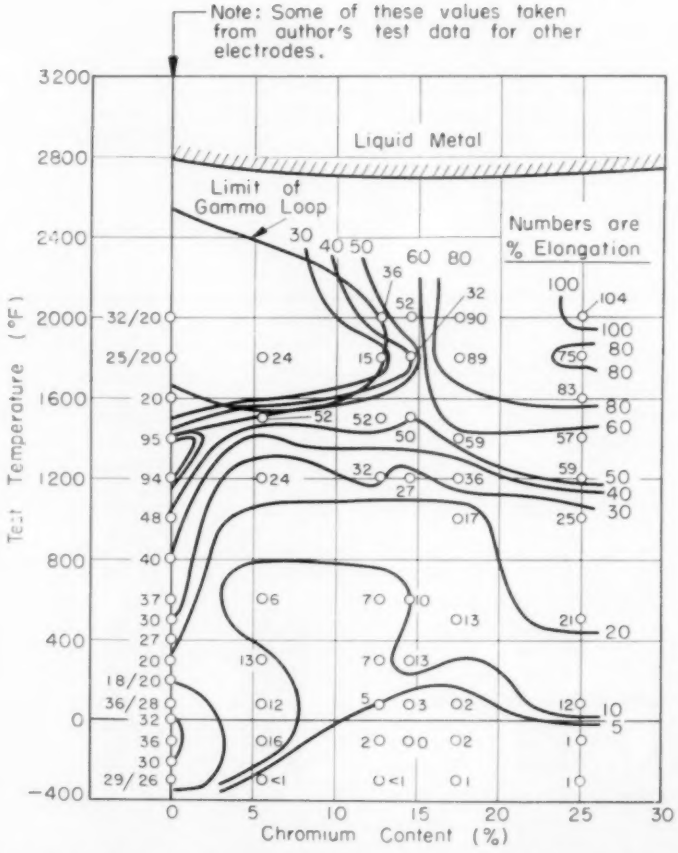

Note: Some of these values taken from author's test data for other electrodes.
Liquid Metal
Limit of Gamma Loop
Numbers are % Elongation
Test Temperature (°F)
Chromium Content (%)

Fig. 4—Iso-elongation lines superimposed upon Cr-Fe equilibrium diagram

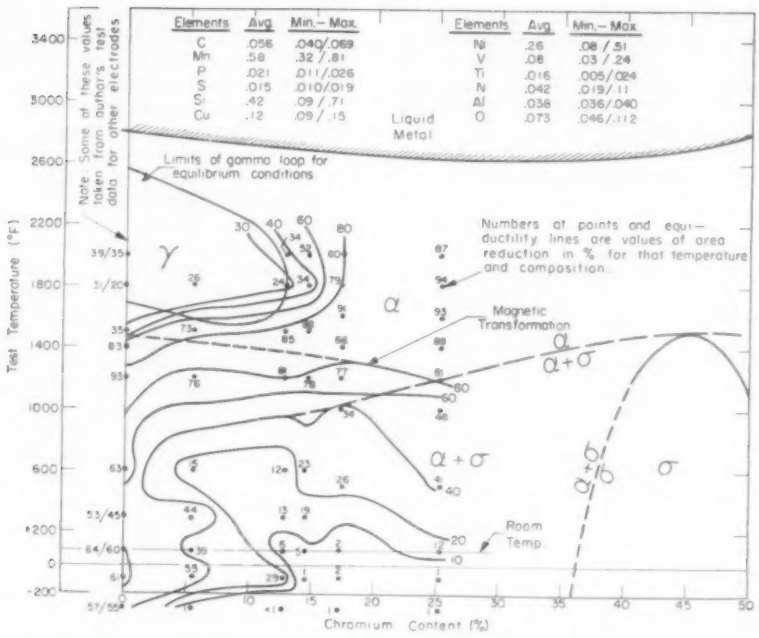

Elements Avg. Min.–Max.
C .056 .040/.069
Mn .58 .32/.81
P .021 .011/.026
S .015 .010/.019
Si .42 .09/.71
Cu .12 .09/.15
Elements Avg. Min.–Max.
Ni .26 .08/.51
V .08 .03/.24
Ti .016 .005/.024
N .042 .019/.11
Al .038 .036/.040
O .073 .046/.112
Note: Some of these values taken from author's test data for other electrodes
Liquid Metal
Limits of gamma loop for equilibrium conditions
Numbers at points and equi-ductility lines are values of area reduction in % for that temperature and composition
Magnetic Transformation
Room Temp.
Test Temperature (°F)
Chromium Content (%)

Fig. 5—Chromium content, test temperature, area-reduction relations for weld metals superimposed upon Cr-Fe equilibrium diagram

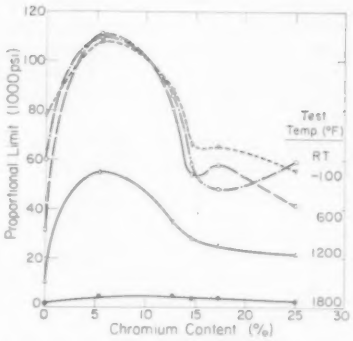


Fig. 6—Influence of chromium upon proportional limit

for the temperatures of 1100° F and above, and it is very low for high-chromium-content welds at temperatures below 600° F. At room temperature, and lower, the total elongation progressively decreases for all additions of chromium to the low-carbon-steel base composition.

The area reduction–composition–temperature relations even more strikingly describe the effect of chromium on as-deposited weld metal, Fig. 5. At the very frigid temperatures, −320 and −100° F, as-deposited low-nitrogen carbon-steel welds, free from chromium, exhibit a remarkable order of ductility.[5] Addition of 5.4% Cr reduces this to near zero at −320° F, and a 14% Cr addition has the same effect at −100° F. Area reductions of 2% and less are secured at those two temperatures for all higher additions of chromium. Low area reductions, 6% and less, are also secured at room temperature for the 12.7 to the 17.4% Cr-content welds. At 600° F, the minimum area reduction occurs between 6 and 13% Cr. At 1200° F, composition has almost no effect on area reduction, which is between 76 and 93% for all compositions between 0 to 25% Cr. At 1500° F, area reduction progressively increases with all additions of chromium to the basic low-carbon steel composition, reaching a high of 88% with the 25% Cr composition. At 1800 and 2000° F, similar very high area reductions were secured for the 17.4 and 25.1% Cr-content welds but for all other compositions, the area reduction values were medium, between 25 and 40%, and particularly for those compositions which undergo the transformation through the gamma phase. The experimental data do not fit the published limits of the gamma loop exactly, but it is known that equilibrium conditions do not exist

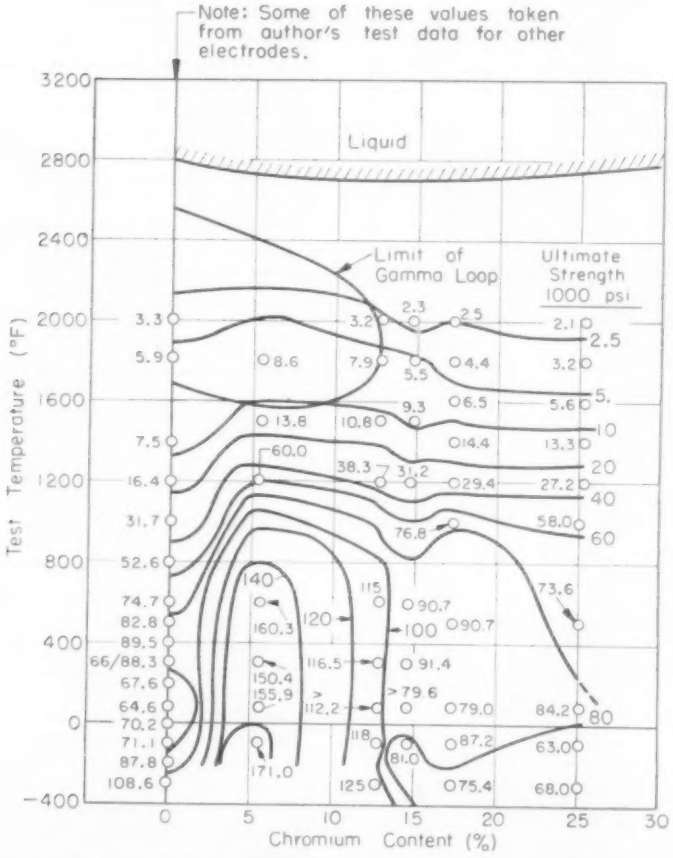

Note: Some of these values taken from author's test data for other electrodes.
Liquid
Limit of Gamma Loop
Ultimate Strength 1000 psi
Test Temperature (°F)
Chromium Content (%)

Fig. 7—Iso-strength lines superimposed upon Cr-Fe equilibrium diagram

during the cooling conditions of the weld. Also, the added alloy content in the commercial weld metals tends to raise the tip of the gamma loop from a drooping to a protruding shape.

There is a general identity in the relationship between the two indexes of ductility—elongation and area reduction—but it is not precise in this instance. Obtained ratios of total-elongation to area-reduction values varied between the limits of 0.31 to 1.20.

By treating the strength data in a similar manner, that is, by relating the proportional limit, yield stress, nominal ultimate stress and true fracture stress values to chromium content, it can be shown that, above 1200° F, chromium content has little effect upon the strength of weld metal, and that the highest strengths are secured near the 5% Cr level, which also contained 0.5% Mo. Below 1000° F, highest strengths are secured with chromium contents between 3 and 13%. For the lesser chromium contents, the strengths are lower because there is less alloy stiffening effect. For the higher chromium contents, the ultimate strengths are less because the weld metals are so brittle that they fail as the result of strain rupture before they reach their potentially available capacity to resist stress. This is an illustration of the two different mechanisms influencing metal strength at a fixed temperature.

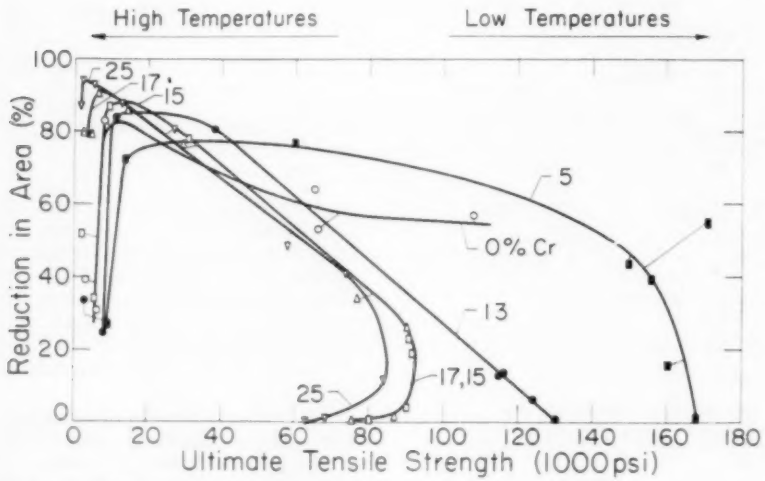


Fig. 8—Limits of strength imposed by ductility

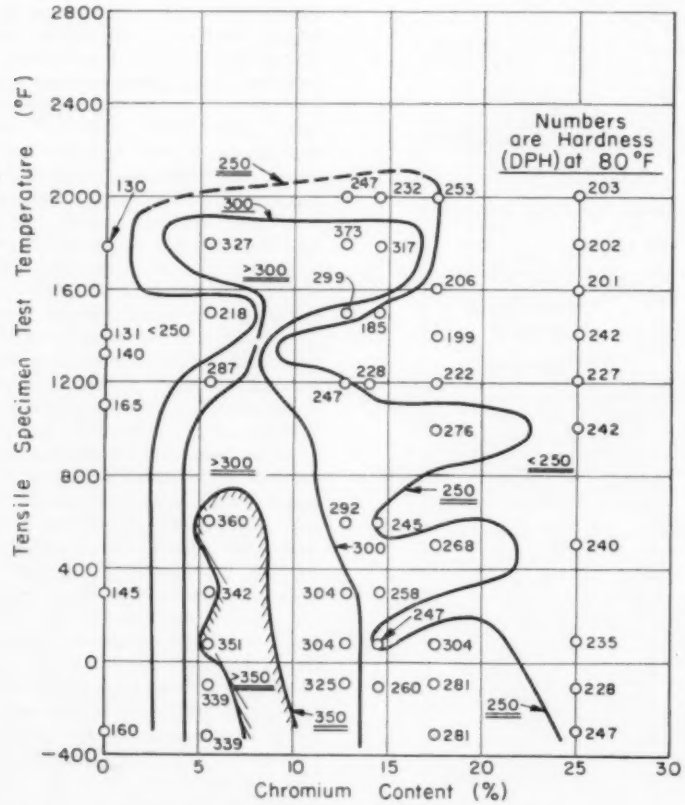


Fig. 9—Relations between final room-temperature hardness of unstrained metal and tensile-specimen test temperature

The proportional limit is, relatively, substantially higher with the 5.4% Cr and 0.52% Mo composition than with any of the others, Fig. 6. Adding chromium and molybdenum to low-carbon steel increases the strength up to that point, and further additions decrease the proportional limit, probably partially because of the increase in grain size and partially because the molybdenum present with the 5.4 and 12.7% Cr-content welds alters the critical cooling rate sufficiently to permit the formation of a martensitic structure. This particular relation is independent of the ductility.

Corresponding plots were not made of the yield stress–chromium content relations but they would be essentially identical in form. For room temperature the yield stress values are:

Cr, %	0.2% yield stress, psi
0.0	55,000
5.4	128,600
12.7	104,000
14.6	71,750
17.4	64,800
25.1	61,900

The relations of ultimate stress to chromium content, Fig. 7, are of the same form as shown for the proportional limit. Again, for all temperatures, the strength is a maximum in the region of 5% Cr. The iso-strength lines clearly depict the trends induced by composition and temperature.

The fracture stresses are also influenced by composition in a manner similar to that of the ultimate strength. Best results are again

secured with the 5.4% Cr and 0.5% Mo composition.

In general, there is an inverse relation between steel strength and ductility, and this is again apparent in the data under discussion. The details of this relationship are further clarified in Fig. 8. The points for each curve in Fig. 8 cover the full test-temperature range, −320 to +2000° F. For the 15, 17 and 25% chromium-content welds, as the temperature decreases, a strength value of about 90,000 psi is never exceeded. At temperatures below which the maximum strength value is obtained, there is no longer a normal inverse relation between strength and ductility. This same condition occurs for the 13% Cr steel welds, but at a stress magnitude of 120,000 psi. The 0% Cr, and the 5% Cr – 0.5% Mo, weld metals decrease in ductility at a lower rate as strength increases with temperature drop. For this test series, the 5% Cr type offers the best strength for a given level of ductility, for all strength levels over 40,000 psi.

At the high-temperature, low-strength side of the scale, Fig. 8, all but the 17 and 25% Cr compositions again decrease in ductility as the strength decreases toward zero, the limiting lower value as the liquidus is approached. In this instance, the indicated reduction of ductility has no influence upon the strength; at those high temperatures, the maximum load resisted is achieved at a strain level of less than 2%.

Hardness

Hardness impressions made on the button heads of the tensile specimens after testing further show the influence of chromium:

Cr, %	As-deposited Hardness, DPH	Retained to ° F	Minimum hardness secured on heating, to: ° F	Maximum hardness secured on heating, to: ° F
0.0	149	1200	1400	...
5.4	346	1000	1500	>1850
12.7	305	600	1200	1800
14.6	252	900	1600	1800
17.4	282	1000	1400	>2000
25.1	237	1400	1600	...

One summary of the hardness values, DPH, taken at room temperature on the tested but unstrained part of the specimens, is shown in Fig. 9. The strongest welds are also the hardest. The high-chromium-content welds that

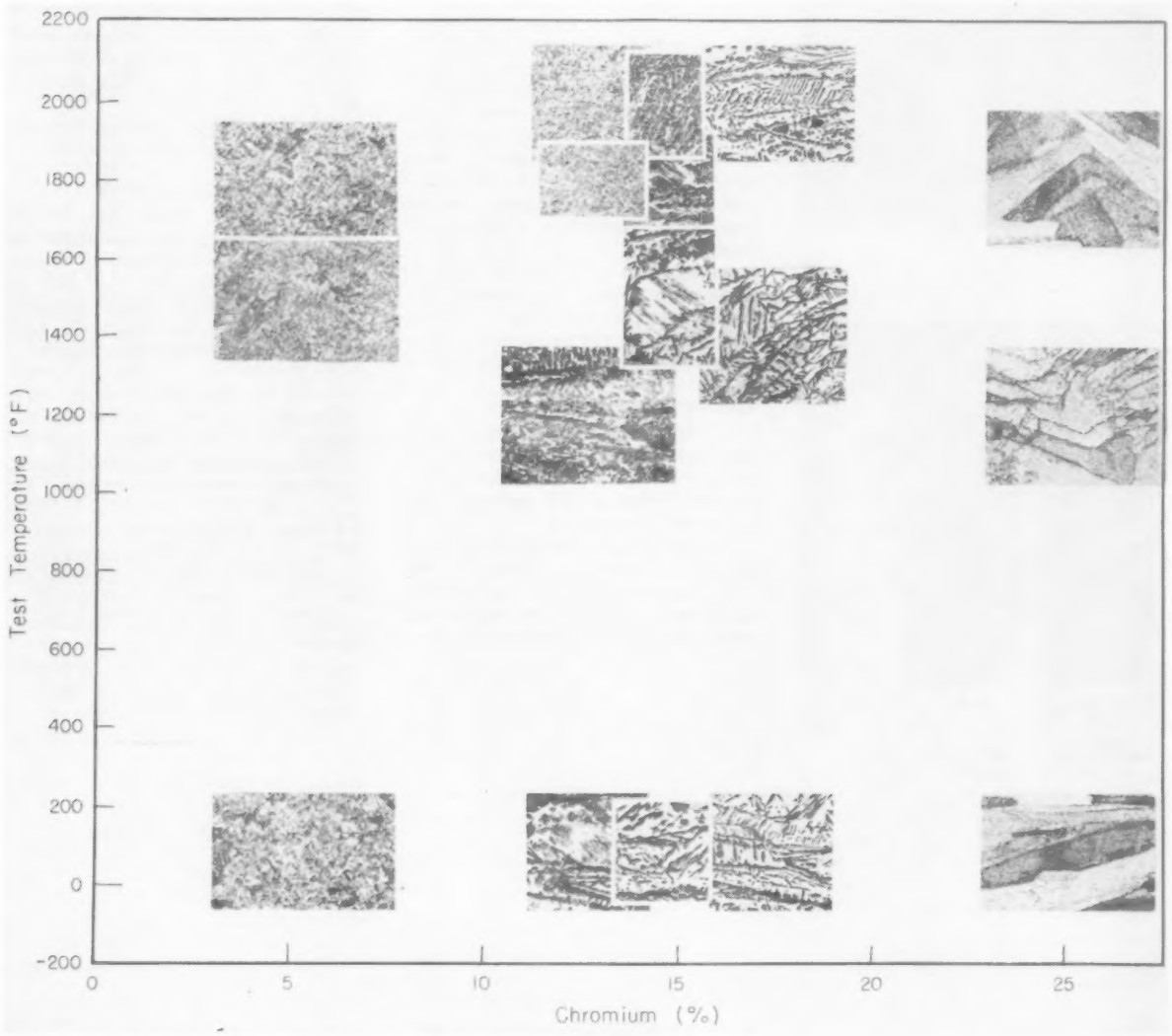
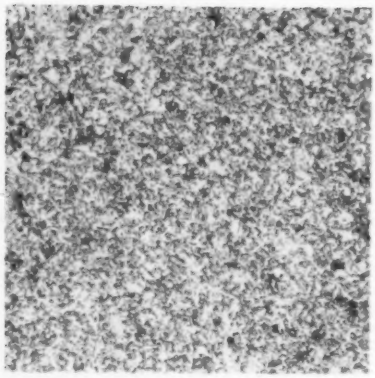
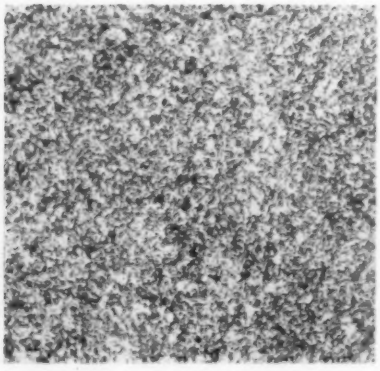


Fig. 10—Change in microstructure with test temperature and chromium content



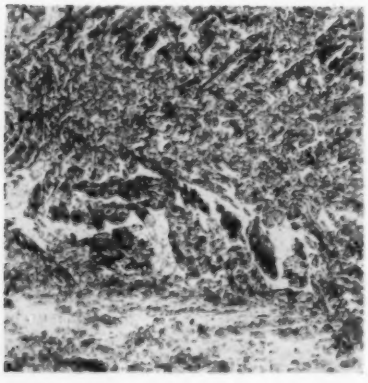
5.4 Chromium

X 100



12.7 Chromium

X 100



14.6 Chromium

X 100

Fig. 11—Structures of weld metals quenched from 1800° F

are low in ductility are medium soft. They typify the classic case of soft brittleness and provide a reminder against too general extrapolations between hardness, strength and ductility. In general, the hardness decreases with increased chromium content for amounts over 5%. Again, this may be partially related to the effect of molybdenum content in the 5.4 and 12.7% Cr-content welds on the critical cooling rate.

Microstructures

The corresponding microstructures of the unstrained weld metals are shown in Fig. 10. Compositions with low-chromium content, less than 6%, are fine grained. As the chromium content is increased, the grain size progressively coarsens.

Heat Treatment

The 5.4, 12.7 and 14.6% chromium-steel welds were treated: 1100° F, furnace cooled; 1500° F, water quenched; and 1800° F, water quenched; Table 2. Both the fracture strength and ductility of the three welds are increased by the 1100° F stress-relief annealing treatment. Even quenching from 1500° F is beneficial for the 12.7 and 14.6% Cr-content welds. Quenching from 1800° F was detrimental for the 12.7 and 14.6% Cr-content welds, although the one containing 5.4% was slightly improved by that treatment. Typical microstructures of these welds, after treatment, are shown in Fig. 11.

Conclusions

1. Of the chromium-steel weld metals, those containing 4–6% Cr along with 0.5% Mo are the strongest and most ductile at near-ambient temperatures.

2. Steels containing 12% chromium, or more, are brittle in the as-deposited condition for all normal temperatures, but retain excellent high-temperature ductility.

3. Steels containing more than 2% Cr should be preheated 700° F, or above, before and during welding to assure adequate ductility in the weld metal during cool-down.

4. All the nonpreheated chromium-steel weld metals in the as-deposited condition tend to be brittle in tension at low temperatures. This implies lower impact values at conventional temperatures.

5. Compositions with less than 13% chromium, and which therefore pass through an alpha-gamma-alpha transformation between 1500 and 2500° F, have lowered ductility within the gamma phase; whereas, higher chromium-content welds that do not undergo such a transformation on heating or cooling have high ductility within that temperature range.

6. Compositions with more than 12% chromium become so brittle at temperatures below 600° F in the as-deposited, nonpreheated condition that they have lowered strength, even though the metal is not hard.

7. The high-chromium-content weld metals are coarse grained.

Acknowledgments

Welds were made by P. T. Ehrhardt, hardness readings by C. J. Dorsch, tensile tests by W. H. Pryle, metallography by R. L. Anderson and chemical analyses by F. P. Byrne, working colleagues at the Research Laboratories.

References

1. Kinzel, *et al.*, "Alloys of Iron and Chromium," *Alloys of Iron Monographs*, Vol. 1 and 2 (1937–40).

2. Thielsch, Helmut, "Physical and Welding Metallurgy of Chromium Stainless Steels," THE WELDING JOURNAL, **30** (5), Research Suppl., 309-s to 350-s (1951).

3. Hansen, "Constitution of Binary Alloys," Second Edition, p. 527 (1958).

4. Heuschkel, J., "Effects of Temperature on Weld Metal Properties," THE WELDING JOURNAL, **33** (8), Research Suppl., 388-s to 397-s (1954).

5. Heuschkel, J., "Dependence of Steel Weld Properties on Lattice Structure," *Ibid.*, **35** (2), 82-s to 90-s (1956).

Temperatures for Rapid Uniaxial Stress Relief of Heat-Resistant Alloys

Hot-test technique is advanced by the author for selecting the temperatures needed to reduce stresses below a selected level

BY HOWARD S. AVERY

Introduction

This paper describes a useful technique for guiding stress-relief heat treating. It is aimed at defining the temperatures needed to reduce stresses below a selected level. The method is particularly useful for the stainless steels and heat-resistant alloys that have relatively high hot strength.

The use of heat treatment to relieve undesirable residual stresses in castings, weldments and other metal structures is common. It has depended largely on experience for the selection of time and temperature factors.

Stress relief is essentially a relaxation or creep problem. Plastic flow, induced by residual stresses and permitted by the weakening effect of temperature, achieves the result. An alloy with unusually high hot strength will respond less to a given treatment than weaker materials. The austenitic Cr-Ni-Fe and related alloy types, because of their relatively high creep strength, will not respond properly to the stress-relief practice that has been developed for common ferritic steels. Where experience is lacking for the high-alloy grades, a technically sound method for deriving stress-relief treatments is needed.

A tedious survey of time and temperature variables on specimens whose "before" and "after" stresses are measured by strain-gage methods would be effective, but this approach is slow and costly. Instead, it is proposed that hindered-contraction or relaxation-test data be used in conjunction with creep-rate data. Creep information is now usually available for the important types and the hindered-contraction test is simple and quick.

The background of the hindered-contraction test described here developed during study of the relative importance of strength and ductility for certain aspects of high-temperature service.[1] While strength is important as a basic design criterion, certain unpredictable factors such as accidental mechanical overloads or thermal stresses may require the ability of a material to adjust to the unforeseen stress pattern. Ductility usually permits such adjustment by plastic flow or relaxation. Response to simple mechanical stresses is evaluated by conventional tension or creep tests. A new technique was employed for the area of thermal stresses.

The volume changes from heating and cooling are a source of trouble. If thermal contraction of an alloy is hindered, either by fixed anchorages or by the rigidity of a casting subjected to differential cooling, serious stresses will appear. Plastic flow will rapidly reduce high initial values to those comparable with the stresses in the vicinity of the conventional yield strength. Thereafter, or for stresses below this, stress relief is slow and is dependent upon the creep characteristics of the material. The limits for rapid stress relief at various temperatures can be determined experimentally[1, 2] by hindered-contraction tests.

Procedure

By heating a specimen (16 x $^{7}/_{8}$ in. diam with a 1 in. x 0.505-in. diam gage length) to high temperature in a tensile machine, applying a small load to remove any slack in the system and then slowly cooling the test bar, the unrelieved stress characteristic of each temperature appears on the load indicator of the machine.* These data are plotted in Fig. 1. In parallel experiments it was found, by arresting cooling at some temperature and by applying an additional load, that within a few minutes the increased stresses were reduced by flow to values corresponding to the temperatures shown in Fig. 1, but stress decrease thereafter was scarcely perceptible. Further

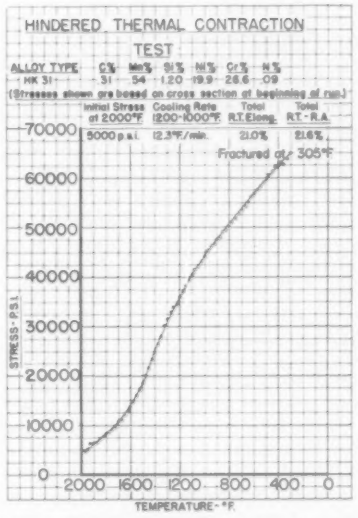


Fig. 1—Typical stresses that develop during cooling of a 26Cr – 20Ni alloy under restraint. This is essentially a graph of yield strength versus temperature

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* Elastic deflection of the lower crosshead, as measured by a dial gage, was compensated, but flexing of the upper crosshead undoubtedly permitted some stress relief not reflected by elongation of the specimen. Except for the first few values, this does not affect the indicated stress.

changes, of course, could have been measured by more precise methods.

The graph of Fig. 2 portrays the trend that is encountered. Essentially, it reveals the level to which stress must fall at a given temperature. A higher stress will promptly cause plastic flow.

As the specimen is cooled and contraction occurs, there is a continuous increase of stress and an associated flow that relieves this stress beyond a critical level. The cumulative flow is reflected by the elongation and reduction of area at room temperature. The specimen may break during this treatment (the HK 31 alloy of Fig. 1 broke at 305° F while the stronger but more brittle HT42 of Fig. 3 broke at 650° F). Other more ductile metals may undergo several such hindered-contraction cycles without failure.

Discussion

It should be recognized that the indicated stresses are calculated from the original cross-sectional area of the gage length. As the specimen stretches, the reduction in area must be applied to rigorous calculations. This can be done if greater precision is required, but for the intended use the temperatures of major interest are those from 1600 to 2000° F, where the flow that has occurred is small.

Examples will clarify the application to stress relief. A short heat treatment at 800° F with the HK31 alloy of Fig. 1 should reduce internal stress to about 50,000 psi. However, this level is too high for most applications, despite the experience that 800° F will effectively reduce residual stresses in carbon and low-alloy steel. Additional time would reduce stress further, but the hindered-contraction plot gives no clue to how much.

Suppose that a maximum residual stress of 10,000 psi is tolerable. From the graph of Fig. 1, this can be quickly attained by heating to 1720° F. Any additional time beyond a few seconds will lower stress even more.

With certain qualifications it is believed that such data can be employed to select effective stress-relief temperatures. The cautions relate to composition, bi- or tri-axial stresses, test details, time and dimensional stability.

Qualifications

By comparison of Figs. 1, 2 and 3, it is evident that data should be associated with a specific alloy. If such information is not available, a test run is advisable. The hindered-contraction data for some of the most important cast heat-resistant alloys are summarized in Table 1.[1-4] These differ from wrought materials of the same nominal alloy content chiefly in carbon content. However, carbon has an important influence on hot strength.

The test, like most engineering measures of strength, typifies uni-axial stress. Higher values can occur in practice with two and three dimensional stresses. With balanced biaxial tension, the data should hold, but for certain ratios of the two principal stresses a critical maximum stress may occur before flow can result. This biaxial yield strength is something like 15% greater than the uniaxial value.[5]

Since restraint may prevent flow in any direction, triaxial stresses can present a case where the yield strength rises to the fracture stress. Usual assumptions may become invalid under these conditions and it is not suggested that the conclusions drawn from uniaxial hindered-contraction tests are applicable. This is an area of stress relief that calls for more research.

The values reported here are related to furnace and specimen design and the rate of cooling during the test. The stresses would probably be approximated in any apparatus that provided sufficient contraction to exceed elastic properties, but the precise values and the elongation observed are expected to be a function of the test-equipment constants. To permit better definition of test conditions, a brief study of isothermal relaxation has been correlated with hindered contraction stresses on a cast HT (16% Cr–35% Ni) heat-resistant alloy. Figure 4 shows the continued fall of stress with time as the continuous cooling of the hindered contraction test was interrupted at

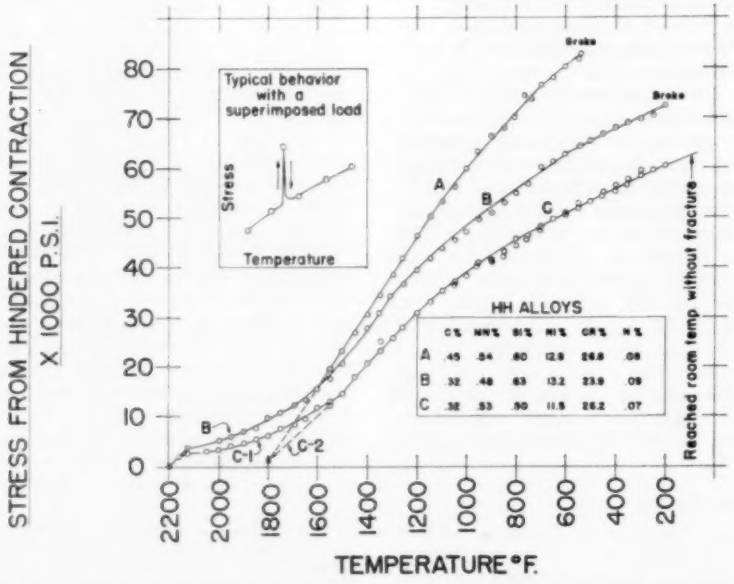

Fig. 2—Hindered contraction stresses of 26Cr – 12Ni alloys as influenced by carbon content and alloy balance. The rapid relief of a superimposed stress is also shown

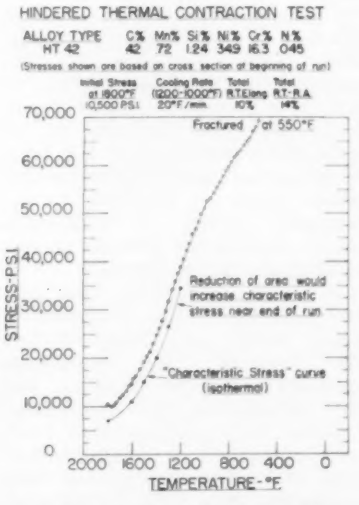
HINDERED THERMAL CONTRACTION TEST
ALLOY TYPE C% Mn% Si% Ni% Cr% N%
HT 42 42 72 1.24 3.49 16.3 045
(Stresses shown are based on cross section at beginning of run)
Initial Stress at 1800°F 10,500 P.S.I.
Cooling Rate (1200-1000°F) 20°F/min.
Total R.T.Elong 10%
Total R.T.-R.A. 14%
Fractured at 550°F
Reduction of area would increase characteristic stress near end of run
"Characteristic Stress" curve (isothermal)
STRESS-P.S.I.
TEMPERATURE-°F.

Fig. 3—The relation of hindered contraction stresses and characteristic stresses from isothermal stress relief tests for 16Cr – 35Ni alloy

Table 1—The Effect of Composition on the Hindered Contraction Stresses of Cast Heat-resistant Alloys

Alloy	Chemical analysis					Hindered contraction stress (psi) observed at										
type	C%	Mn%	Si%	Ni%	Cr%	N%	2000° F	1900° F	1800° F	1700° F	1600° F	1500° F	1400° F	1300° F	1200° F	1000° F	800° F	600° F	400° F	200° F
HF25	0.25	0.96	1.72	7.7	22.3	0.07	...	...	...	...	5,000	10,000	17,000	22,000	25,000	34,000	42,000	49,000	55,000	63,000
HF25	0.25	0.85	0.92	8.7	21.2	0.09	...	...	...	...	12,500	18,000	24,000	29,000	34,000	43,000	51,000	58,000	65,000	72,000
HF28	0.28	0.96	1.15	9.1	20.8	0.09	...	...	...	10,000	13,000	18,000	24,500	31,500	38,000	48,000	56,000	63,000	68,000	77,000
HF34	0.34	0.92	0.48	10.5	19.3	0.11	...	...	...	...	...	8,000	19,000	25,000	32,000	43,000	52,000	61,000	68,000	78,000
HH32	0.32	0.53	0.50	11.5	26.2	0.07	3300	4000	6,000	8,000	10,500	14,500	20,500	25,000	33,500	38,500	45,000	51,000	56,000	60,500
HH32	0.32	0.48	0.63	13.2	23.9	0.09	5000	6500	9,000	12,000	16,000	21,000	28,000	34,000	39,500	47,500	55,000	63,000	68,000	72,500
HH45	0.45	0.54	0.60	12.8	26.8	0.08	...	...	...	...	16,000	23,000	31,000	39,000	46,000	60,000	71,000	80,000	Broke at 540° F	
HK10	0.10	0.87	1.24	18.9	24.2	0.05	...	...	4,500	6,500	9,500	12,500	17,500	22,000	24,500	28,500	32,500	36,500	41,000	47,000
HK14	0.14	1.02	1.22	20.1	24.5	0.10	...	...	...	13,000	14,000	19,000	25,000	30,500	35,000	41,000	45,000	Broke at 750° F		
HK16	0.16	0.96	1.23	20.2	24.5	0.10	...	...	...	...	11,000	16,500	23,000	27,500	32,000	38,500	44,000	50,000	54,000	Broke at 350° F
HK20	0.20	0.92	1.36	21.0	24.2	0.15	...	...	5,000	7,000	10,000	13,500	18,000	25,000	31,500	40,000	46,000	53,500	60,000	65,500
HK26	0.26	0.98	1.23	20.4	26.0	0.11	...	...	...	10,500	15,000	20,000	27,500	33,500	38,500	46,500	53,000	59,500	66,000	73,000
HK31	0.31	0.54	1.20	19.9	26.6	0.09	4500	6000	8,000	10,500	13,500	18,500	25,000	31,500	36,000	44,000	50,500	56,500	62,000	Broke at 305° F
HT29	0.29	0.72	1.28	34.4	16.2	0.04	4125	5750	7,500	10,600	15,250	22,000	29,000	35,125	40,450	48,250	54,500	59,400	Broke at 480° F	
HT42	0.42	0.72	1.24	34.9	16.3	0.05	...	...	10,000	11,500	14,500	19,000	24,500	31,500	39,000	51,000	60,000	67,000	Broke at 550° F	
HT44	0.44	0.74	1.17	35.0	16.2	0.05	4250	5500	7,350	9,750	13,300	18,250	24,750	31,000	36,300	44,750	51,000	56,250	Broke at 480° F	
HT56	0.56	0.80	1.27	34.8	15.9	0.04	4500	5750	7,250	9,300	12,350	16,700	22,900	29,700	37,100	48,750	56,250	Broke at 800° F		

TIME - STRESS CURVE WITH TEMPERATURE AND STRAIN HELD CONSTANT, OBTAINED BY ARRESTING A HINDERED CONTRACTION TEST AT 1500°F.

Fig. 4—Isothermal stress-relief pattern versus time for a 16Cr - 35Ni alloy. The plot extrapolated to zero time gives a "characteristic stress" that should be reproducible in other laboratories

1500° F. Figure 3 shows the normal hindered-contraction graph of stress vs. temperature and a curve labeled "characteristic stress." The latter is based on six time studies at fixed temperatures, like that of Fig. 4. It is believed that the extrapolated value termed "characteristic stress" should be duplicable in different laboratories.

Figure 5 is a composite plot of hot-tensile, hindered-contraction, and creep-test data over the temperature range of maximum utility for stainless-steel stress relief. While it applies rigorously only to the cast 16Cr–35Ni alloy, it shows the relationship of these stress values. It is considered significant that the 0.1 and 0.01% set yield strengths correspond closely with the hindered contraction and characteristic stress values. Both yield strengths and hindered-contraction stresses are arbitrary values based on definition and testing procedure, and probably reflect the same property.

When the values in Table 1 are not applicable and similar data are needed, they can be readily obtained by means of one test. If the time factor is important, one or more characteristic stress checks like that in Fig. 4 can be included. By selecting a value near the maximum tolerable residual stress and holding the test long enough at the indicated temperatures, a pertinent relaxation test is obtained. If the loading apparatus is sufficiently stable, the temperature can be held long enough to provide evidence for the intended heat-treatment time.

Added time may be a liability at the temperatures required by strong austenitic alloys. Unless parts are carefully supported in the

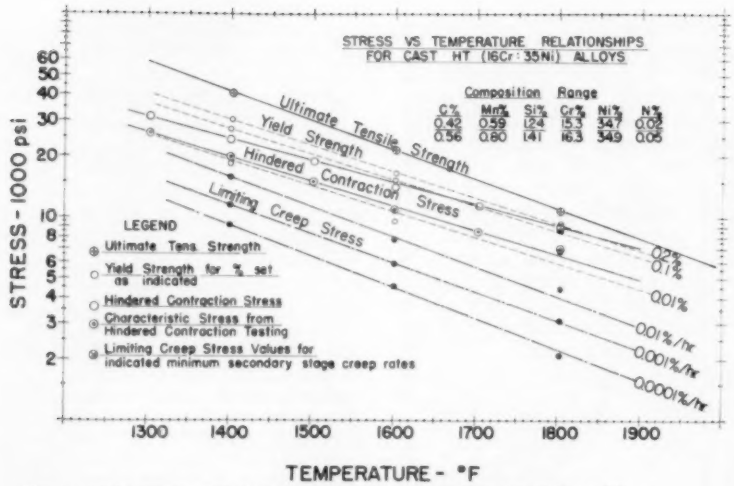

Fig. 5—Wide range plot of stress versus temperature for 16Cr – 35Ni alloys (ACI Type HT50) showing the close relation between hindered contraction stresses and yield strength

furnace, load distortion from creep can destroy a desired dimensional stability. If warping occurs, a part may thus become unserviceable unless it is bent back into shape. The austenitic alloys are ductile enough to permit such straightening, but this operation produces new residual stresses.

Parker[6] has summarized much of the information on the stress relief of weldments. He points out that austenitic Cr–Ni weldments behave differently from those made with carbon or low-alloy steels, for which more stress relaxation data are available. One salient property is usually corrosion resistance, which may be adversely affected by temperatures below the 1900–2000° F range that is employed for toughening by "quench annealing." The range of 1350–1400° F is rated inferior and 1600–1650° F is recommended. About 90% of residual stress is said to be removed at 1650° F. From Table 1 it appears that uniaxial or biaxial stresses should fall promptly to below 14,000 psi (12,000 psi + 17%). With only a few minutes more they should go below 9000 psi, deduced from Figs. 3 and 4. Present evidence does not show the expected stress after relaxation for the 4 hr period suggested by Parker, but it can be established by one hindered contraction test arrested at the selected temperature and held 4 hr.

Since carbon has an important influence on the hot strength of the HF (21 Cr:9 Ni), HH (26 Cr:12 Ni) and HK (26 Cr:20 Ni) cast alloys,* the low carbon levels of wrought 302, 309 and 310 grades are likely to be comparable to the low carbon extremes in Table 1.

* These letter designations are Alloy Casting Institute types.

Note that their stresses are low in comparison with the other cast alloys. Note also that the HF25 and HH32 alloys are weaker than their companions because they are partially ferritic.[1, 4] This sensitivity to composition also suggests the merit of a hindered contraction test to precede any stress-relief program that is important.

Conclusions

The hot-test technique described here is quicker and less costly than time-temperature series, and strain-gage measurements of residual stress. It should be good enough for selecting a suitable temperature for rapid stress relief. The test can be made in any good tensile machine equipped with a furnace for specimen heating.

Acknowledgments

Much of this work was done with the aid of Messrs. C. R. Wilks, James Beckerley and John Ward during a broad investigation of industrial cast heat-resistant alloys. Their efforts and the help of other laboratory personnel are acknowledged with appreciation.

Bibliography

1. Avery, H. S., Cook, E., and Fellows, J. A., "Engineering Properties of Heat Resistant Alloys," A.I.M.E. T.P. No. 1480, *Trans. A.I.M.E.*, **150**, 373–400, 1942.

2. Avery, H. S., and Matthews, N. A., "Cast Heat Resistant Alloys of the 16% Cr – 35% Ni Type," *Trans. A.S.M.*, **38**, 957–1015, 1947.

3. Avery, H. S., and Wilks, C. R., "Cast Heat Resistant Alloys of the 26% Cr – 20% Ni Type," *Trans. A.S.M.*, **40**, 529–584, 1948.

4. Avery, H. S., Wilks, C. R., and Fellows, J. A., "Cast Heat Resistant Alloys of the 21% Cr – 9% Ni Type," *Trans. A.S.M.*, **44**, 57–80, 1952.

5. Gensamer, Maxwell, "Strength of Metals Under Combined Stresses," (1940 ASM Educational Lecture Series), American Society for Metals, Cleveland, Ohio, 1941.

6. Parker, Earl R., "Stress Relieving of Weldments," THE WELDING JOURNAL, **36** (10), Research Suppl. 433-s to 441-s (1957).

WRC Bulletin No. 61

Interpretive Report on Welding of Nickel-Clad and Stainless-Clad Steel Plate

Welding Research Council Bulletin No. 61, published in June 1960, is an Interpretive Report giving the present state of the knowledge of welding of nickel-clad and stainless-clad steel plate. The bimetallic materials which are known as nickel- and stainless-clad steel plates are defined with respect to properties and size. Procedures for cutting to size, preparing edges for welding and fitting prior to welding are described. Some pitfalls experienced when welding clad steels are described and corrective or preventive measures are prescribed. Inspection, testing of postwelding heat treatment, as these subjects apply to clad steel weldments, are reviewed.

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